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Air Traffic Control Advisory Committee, Volume 1

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REPORT

OF

DEPARTMENT OF TRANSPORTATION AIR TRAFFIC CONTROL ADVISORY COMMITTEE

Volume 1

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PRECIS

This report of the Department of Transportation Air Traffic Control Advisory Committee has been approved by the Secretary of Transportation, John A. Volpe, and the Federal Aviation Administrator, John H. Shaffer. The Committee report is to be used ". . . as the basis for a new development program within the Department to initiate the future ATC systems concept" and to ". . . initiate budgetary action to carry out the development concepts contained in the report."

The Committee recommended certain development programs that would lead, with low technical risk, to the following functional system capabilities:

1. A doubling of major urban airport capacity with a likely reduction in perceived noise below current levels;
2. An ability to maintain, if not improve, freedom of flight with greater safety, as traffic increases; and
3. Substantial increases in the ability of controllers to handle traffic through additional system automation.

The Committee considered various air traffic control system possibilities and many technologies. Two major system philosophies were compared; one emphasized cockpit management, the other centralized management of the air traffic control process. The cockpit-managed system relied on air derived collision avoidance. station keeping, and fairly elaborate area navigation equipment. It is doubtful that current collision avoidance systems can have an acceptable false alarm rate and still provide protection in all portions of the airspace. Furthermore, the cost of these systems precludes widespread implementation. Also, it is not possible, emphasizing cockpit management, to achieve the required terminal capacities with reasonable airspace or airport environments. To achieve maximum single runway capacity, it seems both necessary and possible to deliver aircraft to the runway threshold with a 5-second accuracy. This seems feasible only with a centrally managed system.

Three centrally managed systems were investigated, differing in their data acquisition system, one employing satellite sensors, another ground based trilateration, and finally, a ground based rho/theta system.

All satellite systems are specially vulnerable to intentional interference since they must be capable of receiving low power transmissions radiated omnidirectionally from aircraft. Those satellite systems that provide sufficient services (surveillance, communication, navigation) so that a separate ground network would not be required seem beyond the state-of-the-art, but perhaps, in time, achievable with an adequate development program. Less ambitious satellite systems require maintaining both space and ground-based systems. The Committee could not say that the accuracy, altitude sensing, or coverage advantages of satellite systems responded to current ATC problems. No cost advantage is indicated, and the markedly increased vulnerablity is a distinct disadvantage. A ground based trilateration sensor has the marginal advantage of increased en route accuracy, the disadvantage of greater multipath sensitivity (due to its omnidirectional antennas), and terminal siting and coverage problems since at least three sites must have the aircraft in view during low-altitude approaches and departures.

A ground-based rho/theta system has a directional antenna which limits multipaths, can provide sufficient accuracy for the route width required, and utilizes a single site which should simplify low altitude coverage problems. The accuracy and reliability limitation of the ground rho/theta beacon system can be overcome by developing a larger aperture. phased array ground antenna, and by utilizing a discrete address mode rather than the current spatial roll call. The discrete address mode naturally provides a data link to all beacon equipped aircraft. Automation of the radar advisory service in all forms of controlled airspace is a prerequisite to maintaining or expanding freedom of flight with safety as traffic increases. A data link facility is essential to this automation. Thus, of the data acquisition systems considered, a ground based rho/theta, discrete address system seemed most suitable. Fortunately, it is the most readily implemented of all data acquisition systems as a modification to the current beacon.

Airports can achieve approximately a twofold increase in capacity with (1) dual lane runways, (2) microwave ILS, (3) an improved beacon system that incorporates a data link, (4) automation of the terminal radar vector service, (5) reduced separation to 2500 feet between independent parallel IFR runways, and (6) reduced longitudinal separation on final approach to 2 miles. This can be accomplished with safety assuming development and implementation of the data link addition to the beacon system microwave ILS, improved surveillance, and terminal automation systems.

One major urban airport has been studied from the noise capacity point of view, and can operate with these higher capacities and still produce less noise than currently by utilizing (1) lower noise routings through controlled approaches and variable glide slopes permitted by microwave ILS, (2) the quiet nacelle on the P-engine jet fleet, and (3) certain runway reorientations.

The controllers' ability to handle traffic can be increased by proceeding with the plans for the follow-on stages of NAS and ARTS, (1) such as automating IFR separation, sequencing, and monitoring services as well as by automating the radar advisory and terminal vector service with communication automated by data link. Widespread use of area navigation is also recommended as a further aid to the control function.

The Committee was unanimous in its recommendation and suggested a 3-year, $200 million development program to achieve the recommended improvements in the air traffic control system.

(1) National Airspace System and Automatic Radar Control Terminal System.

1. INTRODUCTION

The Department of Transportation Air Traffic Control Advisory Committee(1) was formed in the summer of 1968 for the purpose of recommending an air traffic control (ATC) system for the 1980's and beyond. The Committee's technical staff-made up of some 150 individuals, full- and part-time from all segments of the aviation industry-studied the most critical problem areas. The Committee members met monthly to review accomplishments and guide the ongoing work. In addition to drawing on the FAA, NASA, DOD, and the aviation community for technical staff, the Committee maintained liaison with various aviation organizations, including the military, NASA, AIA, ALPA, AOCI, AOPA, ATA, EIA, NBAA, NPA, and others. Without this broad participation at both the technical and policy levels, the work described in this report could not have been accomplished.

The Committee concentrated on control of aircraft through the airspace, from takeoff to landing. Emphasis was placed on the denser portions of the airspace where the danger of midair collisions and the need for efficient use of scarce resources (principally runways and terminal airspace) make sophisticated ATC mandatory if safety is to be assured without sacrifice of capacity and without unacceptable delays or interference with freedom of flight. Airports were included in the study insofar as they strongly interact with ATC. The Committee's primary concern was with efficient use of runways, while taxiways, ramps, and other facilities were considered only to the extent necessary to understand airport efficiency and real estate requirements. No work was done on airport access. As it became clear that aircraft noise abatement can frequently be obtained by proper terminal routes and procedures, considerable effort was placed on noise reduction which may be critical to community acceptance of high capacity airports.

The conclusions reached on air traffic control for the 1980s and 1990s assume that runway capacity in the dense traffic areas will be provided. This is our present severe bottleneck, and the improvements to the ATC system discussed in this report will not be significant unless the airport (runway) problems are also resolved.

The Committee elected to place minimal effort on over-ocean ATC and communications in view of the apparent adequacy of existing technology and the straightforward nature of the problems. Further, the Committee postulated a fundamental requirement that the ATC system of the future should not significantly constrain the growth of aviation.(2) The specific requirements which derive from this are performance and cost characteristics which permit all of the users to maintain activity levels close to what they would have been if the cost were much less or the performance much greater. While this approach to establishing system requirements has its limitations, it has proved workable and equitable at this stage of aviation's growth.

Air traffic control is now ending its second generation.(3) The present manual system is soon to be supplanted by the semi-automatic Third Generation System, which follows guidelines recommended by Project Beacon in 1961.

In order to understand the problems of transitioning to a new system in the 1980s, the Committee studied the performance of the Third Generation System with the projected traffic loads. It became apparant that the Third Generation System, as presently planned, must be substantially upgraded if it is even to accommodate the aviation growth of the1970s. Studies of feasible modifications show that it is entirely reasonable to select an upgrading program which can greatly extend its useful life. Moreover, this upgraded Third Generation System, in compari-

(1) Committee members, affiliations, and titles are listed in Appendix A.

(2) This does not mean that the Committee favors implementing ATC improvements to meet peak demands independent of their costs or the users' willingness to pay, nor does it imply that the Committee rejects the use of differential pricing or route and scheduling restrictions to obtain maximum benefit from the ATC and airport systems at various stages of their development. These questions of policy are considered to be outside of the Committee's charter.

(3) See section 3.4.1 for a description of the Second and Third Generation Systems.

son with alternative approaches, appears capable of providing the capacity needed with fewer compatibility problems, less technical risk, and at lower cost. By implementing these modifications progressively, it should be possible to accommodate the traffic as now projected into the 1990s. The Committee strongly urges this path be followed, and most of this report is concerned with upgrading the Third Generation System. Near the end of the century, a Fourth Generation System may be needed. This report identifies major innovations that such a system might include and suggests fundamental studies needed in advance of any development effort.

While the Committee is recommending specific system characteristics and is proposing a number of high priority system engineering and development programs, it has not attempted detailed designs, nor has it considered specific deployment plans. Nevertheless, it is clear that the approach recommended mill require an investment of several billion dollars during the 1970s in ATC development and facilities. Additional billions will be needed in the 1970s for airport improvement and nem construction if the demand is to be accommodated.

The Committee is concerned that the system recommended by Project Beacon in 1961 will not be completed before 1973. An early review is urged to determine the new organizational and contractual arrangements necessary to ensure the timely completion of a program of the magnitude and urgent national priority recommended in this report.

2. SUMMARY OF SYSTEM RECOMMENDATIONS

THE CRISIS

Air traffic is in crisis. The crisis now manifest at a few high density hubs is the direct result of the failure of airports and air traffic control capacity to keep up with the growth of the aviation industry. With proper leadership, funds, a sense of common purpose in the aviation community, and steps taken to promote coexistence between airports and their neighbors, this deficit can be eliminated through intelligent application of recent advances in aeronautics, electronics, and computer science. Unless strong measures are taken, forces presently in motion will blight the growth of American aviation.

The demand for all categories of aviation will maintain its high growth rate unless further constrained by an inadequate air traffic system. The various national indices of aviation activity are predicted to at least double by 1980 (with respect to 1968) and to double again by 1995. Five airports now operate at saturation during peak hours. This number will rise to twenty by 1980 unless present expansion plans are accelerated. The demand for ATC service will rise even faster than aviation activity in general. Overall, the demand for ATC service is estimated to almost treble by 1980 and to treble again by 1995.

In light of this projected demand, the Committee sees three critical problems which urgently require solutions if aviation growth is to be accommodated :

1. The shortage of terminal capacity;
2. The need for new means of assuring separation;
3. The limited capacity and increasing cost of ATC.

UPGRADING THE THIRD GENERATION SYSTEM

The semiautomatic Third Generation ATC System, originally recommended by Project Beacon in 1961, is now being implemented. It will initially become operational in 1971 and will be in widespread use by 1973. Because of the slow pace of implementation, and unforeseen aviation growth, it now requires major modification if it is to solve the crucial problems that the Committee foresees for the late 1970s and beyond.

Terminal Capacity

The airport plant at a number of dense hubs is often saturated by the present demand at peak hours. There will continue to be popular resistance to construction of new airports in major urban areas as a result of their high costs, the diffuse distribution of the benefits of aviation activity, increased noise, and political fragmentation. As a consequence, it is not reasonable to expect additional urban airports sufficient in number to satisfy the forecast demand even if increased use of V/STOL is taken into account. Major improvements in current airport capacity must be achieved. For public acceptance, this should be accomplished without increasing perceived aircraft noise.

Committee studies show that it is possible to more than double the capacity of present airports. By the use of newer techniques of instrument landing, surveillance, and ATC, additional runways can be brought safely into use and all runways made to operate at higher capacity. The same principles can be applied to new airport construction to provide greater capacity than airports as presently designed.

The dual lane runway provides a 40 percent increase in capacity using present separation standards. Automation beyond that presently planned would increase runway capacity by an additional 30 percent. Decreasing aircraft longitudinal separation to two miles could provide still another 40 percent increase in capacity. Thus, dual lanes, automation, and decreased separation could provide more than a two-fold increase in runway capacity. Furthermore, additional capacity can be provided by utilizing airport acreage more efficiently by decreasing the 5,000-foot separation between independent IFR runways. The Committee believes it will be possible to safely reduce this separation between runways to 2,500 feet and the final spacing on approach to two miles. This will require an improved landing aid, such as the scanning beam microwave ILS, as well as provisions for precise monitoring and data linked commands in case of blunders These requirements, along with increased terminal automation, are included in the upgraded Third Generation System. While procedural techniques can probably be devised to permit the recommended separations despite wake turbulence, means may be required for predicting, sensing, or dissipating dangerous wake turbulence. The Committee's wake turbulence dissipation studies have shown promise.

Curved routes to airports, made possible by a scanning beam microwave instrument landing system, can reduce public discomfort caused by aircraft noise Moreover, the quiet nacelle program has shown encouraging results. By incorporating low noise routing plus engine quieting, a preliminary study of Kennedy Airport indicated noise could be reduced even though traffic was doubled.

Separation

The current use of radar and ATCRBS(1) data to assure separation has largely eliminated collisions between aircraft when both are under radar control. In recent years, however, collisions between air carriers under control and uncontrolled aircraft have averaged more than two per year. Since the likelihood of such collisions approximately rises as the square of the aircraft population, measures beyond the present use of "see-and-avoid" in portions of "Mixed Airspace"(2) will become mandatory by 1980. Committee studies predict a collision rate of 10 per year in 1980 in Mixed Airspace (between air carriers and general aviation) unless changes are made. Furthermore, the collision rate between uncontrolled general aviation aircraft (33 in 1968) will also grow rapidly unless improved means of assuring separation are provided.

The Committee believes it is now feasible to largely overcome the mid-air collision problem in portions of the airspace under surveillance without significantly restricting freedom of flight. The strongly preferred approach to this lies in automating and making more precise the air traffic advisory service. Additional protection may be available through cockpit visibility improvements, conspicuity enhancement, and possibly PWI or CAS(3) devices.

By means of a data acquisition system that reliably and accurately provides the ATC center with identity, position and altitude information on all aircraft within designated portions of the airspace, the ATC computer, through a data link, can automatically advise aircraft of threats due to other aircraft, weather, airspace boundaries, and surface obstacles. In addition, instead of merely advising of threats, the computer can generate commands for appropriate evasive maneuvers. This process is called Intermittent Positive Control (IPC) .

Under IPC, conflicts between aircraft under surveillance, controlled or uncontrolled, would be predicted, safe maneuvers calculated, and appropriate commands automatically transmitted to the aircraft and displayed to the pilot. The additional ATC computer equipment required to provide this service is relatively modest. No controllers would be required. IPC need only be applied when a collision is possible; otherwise, all aircraft would follow normal procedures.

IPC requires aircraft in the airspace served to be equipped with a simple ground-to-air data link and display, in addition to the beacon transponder. In the upgraded Third Generation System, this IPC data link and display should be a low cost integral part of the beacon transponder.

IPC appears applicable to traffic densities as high as that predicted for the Los Angeles Basin in 1995. Even there, assuming completely random flight, IPC is estimated to require only five commands per hour per VFR aircraft. At intermediate densities, only aircraft wishing separation service need have data link (although all must be transponder equipped). While substantial amounts of ground computations would be required for IPC, the increasing capacity and decreasing costs of computers will make IPC quite practical in the late 1970s and beyond. In some portions of the airspace, the information and instrumentation needed for IPC could be used to mark the boundaries of uncontrolled air routes ("VFR Highways"). The additional order such routes provide is likely to permit high density flights without the collision risk that would otherwise be expected at such densities.

While the Committee recognizes that requiring all users of the denser portions of mixed airspace to be transponder equipped will be burdensome to some, it sees no feasible alternative if aviation growth is to be accommodated at acceptable levels of safety. The service provided will more than justify the cost.

(1) Air Traffic Control Radar Beacon System.
(2) "Mixed Airspace" has come to be used by the Committee to denote airspace shared by controlled and uncontrolled aircraft.
(3) Pilot Warning Instrument and Collision Avoidance System.

Automation

A third problem relates to limitations in the control process due to (1) the potential scarcity of controllers and (2) the saturation of manual control at major hubs.

There are now about 16,000 highly skilled controllers, excluding supervisors, employed by the FAA. The 1968 controller labor cost was $0.25 billion. The number of controllers required increases at least directly with the traffic. Despite the limited automation of the Third Generation System presently being implemented (NAS Stage A and ARTS III (4)), the FAA estimates that more than 33,000 controllers will be needed by 1980, and costs will rise at least in proportion. It may be extremely difficult to maintain such a work force and, even if possible, costs may rise sufficiently to jeopardize public acceptance.

The problem of saturation of the manual control process is especially serious in the transitional airspace between en route and terminal regions. In New York, certain of these sectors are already operating at saturation. While it is possible to alleviate this problem somewhat by rerouting and resectorization, New York, and possibly other hubs, will be in serious difficulty before 1980 without more automation.

The Committee studied the effects of increased automation in the New York terminal area; it believes the results can be extrapolated to other regions. One conclusion was that, by expanding the semiautomation of NAS Stage A and ARTS III to include spacing, sequencing, and conflict prediction and resolution, and by adding data link, two to three times the present traffic could probably be handled by the same controller work force. The introduction of automatic IPC to assure separation may prove sufficiently successful and reliable that controller efficiency may be increased even further. Resectorization and nondirect routing, taking into account a widespread area navigation capability, may unload the busiest sectors so as to increase capacity by an additional factor of two to three, but with a proportionate increase in the number of controllers.

By these means, the control function of the upgraded Third Generation System can be made to handle the traffic projected for the 1990s. Should higher levels of automation prove feasible, it would be possible to handle the traffic of the 1990s with fewer controllers.

Data Acquisition/Data Link

The current data acquisition system is working effectively and receiving wider user acceptance. Difficulties experienced during its implementation are being overcome. However, to provide the accuracy and speed of response required for monitoring close spaced approaches and the interference free capacity that will be needed when all aircraft in dense airspace are transponder equipped, substantial modifications will be needed.

Data link is clearly a requirement. Air-to-ground communications for the Third Generation ATC System under present plans is limited to VHF voice. While ATCRBS automatic identity and altitude reporting will unload the controller somewhat, FAA studies indicate that controllers' communications workload may seriously limit the increased efficiency available from automation. Furthermore, an automatic separation assurance function, such as IPC, requires at least a ground-air data link.

The Committee believes that the ATCRBS system should be upgraded by (1) providing for the use of phased array interrogator antennas in the denser hubs to achieve enhanced accuracy and data rate, and by (2) including an additional "discrete address" mode(5) to increase capacity in the denser regions. The addition of this mode would permit the simple addition of two-way ATC data-link service with ample capacity for the traffic forecast for 1995. Thus upgraded ATCRBS could provide a common data acquisition/data link system which would operate nationally on a single channel.

The Committee has conducted preliminary system design studies and finds a number of ways to perform this upgrading which differ in the degree to which they modify the present system. All of these approaches, however, are compatible with continued use of the transponder equipment presently being produced. Comprehensive system engineering is required to specify the upgrading program in detail.

Many members of the aviation community believe ATCRBS should be upgraded along these lines. There are others who believe that a new system using multilateration should be introduced in parallel with ATCRBS and should then gradually supplant it.

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(4) National Airspace System and Automatic Radar Control Terminal System are descriptive of the automation being implemented in the present Third Generation System. See Section 3.4.1.

(5) Only designated aircraft are interrogated.

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The Committee has compared these approaches and unanimously agrees that the ATCRBS should be upgraded rather than replaced. This conclusion is based on studies of (1) feasibility and cost of incrementally and compatibly upgrading the ATCRBS, and (2) technical risks(6) and incompatibility of the various multilateration systems.

Navigation and Landing Aids

The VORTAC navigation system, while less accurate and more wasteful of bandwidth than modern technology could provide, can be compatibly and incrementally upgraded so that it will present no impediment to the growth of aviation before the 1990s.

It is possible to navigate routes separated by two miles near busy terminals utilizing VOR/DME area navigators and modern flight directors assuming monitoring by the upgraded ATCRBS.

A navigation feature is available in the data link/data acquisition system. Because the location of all equipped aircraft is known continually to the ground computer, position information can be made available to the pilot on request via the data up-link. The navigation accuracy would be better than 1/2 mile anywhere in the service area. It is not suggested that navigation information derived in this matter substitute or replace the basic VOR TAC system. It should prove useful, however, for updating a dead reckoning system or confirming and/or refining any other air-derived position information.

The Committee recommends rapid implementation of the scanning beam microwave ILS. It provides (1) increased accuracy and reliability due to freedom from site and overflight effects, and (2) guidance information for curved approaches and variable glide slopes, all leading to increased capacity at minimum noise levels.

Backup System

The lives of tens of thousands of people may depend on the continuity of operation of the ATC system. The inherent reliability, redundancy, and recovery modes from failure must be designed with extreme care.

The ATC equipment must be designed so that massive ground failure is extremely unlikely. The equipment must be inherently reliable and be designed to withstand external failures, such as power loss and lightning. It must be engineered for sophisticated preventive maintenance. It must be installed, operated, maintained, and frequently tested so as to ensure that the design reliability is achieved.

The ATC system must be able to recover from (1) failure of portions of the ground environment, (2) failure of airborne equipment, and (3) an aircraft's deviation from its prescribed flight path. The design of these recovery modes becomes more demanding as traffic density increases. Multiple coverage should be the prime recovery mode to ground failure, i.e., each center should be backed up by neighboring centers and major terminals within the center; critical data acquisition sites should be covered by neighboring sites; terminals would be backed up by the center.

Emergency procedures for safe recovery from failure should be an integral part of the original system design. Recovery actions in which both pilot and controller must participate should be well understood and frequently simulated by all participants. The procedures for such rare failures need not be all expeditious nor need they be as safe as measures that would be used normally.

The Committee considered the need for mandatory autonomous backup airborne equipment, such as stationkeepers. It is inclined to the belief that overall ground system reliability plus emergency recovery procedures will be sufficiently effective to render such equipment of doubtful value. This, however, only reflects the Committee's judgment, since no comprehensive study of the relationships between system design and recovery modes is available.

Radar skin tracking is now assuming a backup, rather than primary, role as the implementation of ATCRBS proceeds. In this role, it backs up the ground interrogator as well as providing skin tracks on aircraft without operable beacons.

Radar is still extremely useful in NAS and ARTS tracking functions when ATCRBS data is missing due to aircraft shielding, or poor data reliability due to over-interrogation, garbling, or fruit.

Even though ATCRBS reliability is improving, until such time as multiple antennas are installed on larger aircraft, transponder replies will fail routinely on certain departure and approach routes, and automation programs will use radar data in this portion of the airspace.

As traffic density increases, the cost of correlating radar data and ATCRBS data to find the unequipped intruder or failed equipment becomes substantial, and costing perhaps more than trans-

(6) Primarily multipaths and siting problems.

ponders on all aircraft that would not otherwise require them. Wider implementation and increased reliability of transponders will reduce the threat of the unequipped intruder and, in time, render a primary radar system unnecessary for air traffic control, although its use for air defense and weather data may continue.

There is a procedural response to airborne equipment failure. Backup procedures using radio communication and VORTAC can be initiated with the aircraft whose transponder or data link has failed.

The Committee endorses steps being taken to encourage widespread adoption of the transponder. The FAA should also consider the possibility of requiring transponders as initial equipment on all new aircraft. Larger aircraft should carry multiple beacon antennas to assure reliability of the data acquisition system during turns and climb/descent maneuvers.

The air derived collision avoidance system (CAS) has been suggested as a means for protecting against an aircraft which has deviated from its prescribed flight path, either because of an aircraft failure or an ATC system failure. While such might prove satisfactory for isolated or momentary failures, the CAS has never been proposed as a substitute for the ground based ATC system.

For CAS to serve its intended purpose in an isolated or momentary failure, it is important that the CAS alarm region be less than the ATC separation being employed, otherwise its false alarm rate and interaction on ATC would be unacceptable. The separation employed by ATC is determined by the accuracy and data rate of the ATC data acquisition/data link, and the response time of the control and aircraft systems. There is some doubt that the CAS alarm region can be made sufficiently small for all airspace in a system based only on range and range-rate information. This will become more critical as traffic density increases and as ATC separation standards are decreased. The exchange of additional information in the CAS may help, but this complicates the equipment further and would add to its cost, thus limiting the possibility of widespread adoption. Without broad implementation, there is little utility to CAS. In spite of this limitation, the Committee recognizes that some airlines may elect to implement CAS. The FAA should study CAS performance to determine to what extent it may be a useful supplement to the ATC system.

The Recommended Upgraded Third Generation System

In summary, the recommended upgraded Third Generation System includes (1) scanning beam microwave ILS for landing and terminal navigation, (2) airports that are designed for high capacity, (3) improved VOR/DME for en route and terminal navigation with wide implementation of area navigation, (4) a discrete addressed ATCRBS that incorporates an integral data link (of varying sophistication, depending on the aircraft) and that employs phased array ground interrogators, (5) automatic IPC, at least in the denser portions of Mixed Airspace to safely handle increased traffic while maintaining freedom of flight, (6) an increased capability of NAS/ARTS as far up the automation ladder as becomes possible, and (7) a coupling of the control function to aircraft via data link.

PLANNING FOR THE FUTURE

Fourth Generation System

While the upgraded Third Generation System appears able to handle the traffic estimated into the1990s, it is likely to exhibit significant deficiencies before the end of the century; specifically:

1. The semi-automatic control process may be near saturation at major hubs, and nondirect routing may be required at peak hours to achieve capacity.

2. The controller population, in spite of the added efficiency provided by a fully implemented NAS/ARTS, may have grown to 35,000 or more.

3. Route separation requirements, especially in transitional airspace, imposed by navigation errors may force additional noneconomic routing and many contribute to control system saturation.

4. Accuracy and coverage of navigation and surveillance may be inadequate to meet V/STOL air carrier needs and also inadequate to meet both general aviation and the air carriers' needs in remote areas.

5. The improved DME system may be at the limit of its capacity.

While ad hoc fixes could be used to overcome some of these deficiencies, the Committee feels a Fourth Generation System should be in orderly development which can supplant the upgraded Third Generation System.

Possible components of a Fourth Generation System were studied using twice the demand forecost for 1995. The total U.S. fleet was assumed to consist of one million aircraft, with a peak instantaneous airborne count of 100,000. This fleet was almost all general aviation aircraft, but the one percent which is air carrier made 10 percent of the flights and generated 80 to 90 percent of the passenger-and-crew miles.

Universal coverage, improved system accuracy, and much higher levels of automation, if feasible at reasonable cost, could overcome the long-term projected deficiencies of the upgraded Third Generation System. The Committee's review of future possibilities identified space and computer technology as offering the greatest potential advantages.

A More Automatic ATC System

To obtain an understanding of the feasibility and cost of proceeding towards a greater degree of automatic ATC operation, a study was made of the Los Angeles Basin under the design conditions for the Fourth Generation System. The en route area (approximately 400 x 800 miles) was assumed to have an instantaneous airborne count of 8,000. Of these, 4,200 were in the terminal area, a region 60 x 120 miles in area by 10,000 feet in altitude. Within this region were 12 high-density terminals. The study was limited in that it did not address the problems of the highly sophisticated logic that wouid be required for full automation, or the difficult software problems involved. It did, however, assess in detail the computer requirements for all of the calculations that would be required once a specific control strategy had been selected. The conclusion was that the computer technology of 1975 will be adequate to cope with twice the projected 1995 traffic. The computer costs for automation of the Los Angeles Basin, both terminal and en route, for the traffic defined above were surprisingly low-less than $50 million.

Adding the functions of conflict prediction and resolution, spacing, sequencing, and metering with ground-air-ground data link to the semi-automatic NAS Stage A and ARTS III automates all normal ATC functions. But this is not the limit to automation possibilities. A higher level of automation would have the controller provide system status inputs such as weather and wind shifts, blocked runways, aircraft emergencies, and ATC equipment failures, so that the ATC system automatically accommodates to these inputs in directing traffic. Such a higher level of automation requires a system design and reliability (both software and hardware) such that no emergency could develop that could not be resolved by the man-machine combination. In such a system, man is the manager and exercises strategic control of the system. Whether the upgraded Third Generation System could be used in this manner can only be answered after accomplishing the recommended research and development program.

The initial studies of automatic IPC for Mixed Airspace seem sufficiently promising that applications of IPC to those positive control sectors where merging and sequencing are infrequent should be thoroughly tested.

In addition, the Committee recommends the prompt initiation of a system study that determines whether the higher levels of automation achieved by the incremental additions to NAS/ARTS would be fundamentally different from an automation program that was derived from basic considerations of air traffic flow capacity and safety.

In summary, the Committee recommends three parallel approaches toward higher levels of automation:

1. Incremental, but rapid additions to the NAS/ARTS program for positive control and dense terminal airspace;
2. IPC for Mixed Airspace and possibly some positive control regions;
3. Fundamental studies of higher levels of automation.

Satellite Systems

Three-dimensional position accuracy of a hundred feet and universal coverage appear attainable from a properly designed satellite system. Because of relatively high elevation angle, satellites can have less multipath involvement than any ground based sensors.

The airborne component of such a system might be comparable in cost to present transponders if all computations were performed on the ground and relayed via satellite to the users, and the satellites employed high power and highly directive antennas.

A satellite based system might contribute to solving such perennial aviation problems as low-altitude navigation and surveillance for V/STOL aircraft, separation assurance for air carriers engaged in infrequent services to low density regions, the need for approach aids at remote airports. (7)

(7) In addition to aviation, there will be a wide range of users for a precision navigation-surveillance-data system which does not suffer the usual line-of-sight restrictions. Marine search and rescue, police and fire, and many military users could be compatibly served at data rates which would add little additional to the aviation load.

The Committee considered one such system employing a constellation of five synchronous satellites designed to serve all the CONUS airspace, provide up to 100,000 instantaneous participating aircraft precision navigation (including altitude), data acquisition, and ATC data link services. The annual cost for the satellites and associated ground equipment appears to be less than $100 million.

The major technical and operational problems relate to (1) the development of signal processing system adequate for the traffic within a reasonable bandwidth, and (2) achieving the reliability demanded of a system that is concentrated as compared to the current diffuse system, especially immunity from failing catastrophically due to hostile human acts. The Committee recommends a research program relating to these problems.

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3. THE SETTING AND REQUIREMENTS

3.1 DEMAND

The Committee has used the usual techniques of system analysis to develop our recommendations. Forecasted user needs define requirements; various system alternatives are developed to meet these requirements; a preferred system is selected on the basis of cost, technical risk, implementability, and performance.

The Committee postulated a fundamental requirement that the air traffic control system of the future should not significantly constrain the growth of aviation. The specific requirements permit all of the users to maintain activity levels close to what they would have been if the cost were much less or the performance much greater. While this approach to establishing system requirements has its limitations, it has proved workable and equitable at this stage of aviation's growth.

In this section of the report forecast is prepared of ATC demand, Section 3.1; the implications of meeting this demand are derived for various portions of the air traffic system such as airports, Section 3.2, various categories of airspace, Section 3.3, and the ATC system itself, Section 3.4.

Requirements on each portion of the air traffic system flow from the demand and from the safety and cost implications of meeting demand. Demand in any region dictates the required runway capacity of that region, which in turn prescribes the regional airport configurations and the runway capacity of each airport. From the deployment of runways, their required spacing and acceptance rates, come the specifications for landing aids, terminal navigation and data acquisition systems, terminal control functions and the design of the terminal airspace itself.

Reiterations of the system design cause reconfiguration of runways and terminal airspace based on the capabilities of aircraft, landing aids, terminal navigation, data acquisition and control systems.

The remainder of the airspace and ATC system is derived from the requirement to feed terminal airspace safely and efficiently.

3.1.1 Methodology

Estimates of air traffic activity are developed below for 1968,(1) 1980 and 1995. For 1980, FAA-prepared forecasts of air carrier and general aviation (2) aircraft requirements were used as the base from which the activity measures were developed (Reference 1). The 1995 estimates of civil aircraft inventories were prepared for use in this study and coordinated informally with the FAA and interested industry groups.

The FAA does not forecast numbers of aircraft in the military inventory. For purposes of this study, a U.S. based military fleet of 20,000 aircraft was assumed up through 1995 to reflect joint use of airspace by both military and civil users.

Using the forecasts of fleet size and utilization as a base, estimates of annual flying hours, flights, operations, and peak airborne aircraft counts were developed in the following manner:

Flying hours-numbers of aircraft multiplied by annual utilization.

Flights-flying hours divided by flight duration (hours per flight). Total flying hours by each aircraft type were distributed between a local and an itinerant component before converting hours to flights.

Operations-flights multiplied by operations per flight.

Peak minute airborne aircraft-numbers of aircraft airborne at peak times were estimated by applying busy day and peak minute factors to annual flying hours.

Forecasts prepared in this way are estimates of the total activity of all airspace users, civil and military, and at all airports, tower and non-tower. Today, only about one of every two flights makes contact with the air traffic control (ATC) system. As larger, better equipped aircraft enter the in-

(1) Activity at non-tower airports was estimated for 1968, as was most airborne activity.

(2) General aviation is a generic term for all civil non-air carrier flying. It includes such diverse activities as personal, executive, business, aerial application, instructional, air taxi, and industrial/special flights.

ventory, it is anticipated that more and more users will take advantage of the services offered. Safety considerations also may require more participation in the ATC system.

For system design and long-range planning purposes, therefore, forecasts of total aircraft activity are more useful than projections of the activity of selected users or of loads on ATC facilities. Total activity provides a baseline from which to estimate the impact of new rules and operating procedures on airspace users and facility requirements. Detailed development of the estimates is described in Appendix G.

These estimates of air traffic activity are based on forecasts of demand unconstrained by the airport or ATC systems of the future. This implies the provision of sufficient airport and ATC/NAV facilities to handle the increased traffic loads. Potential impediments to unconstrained growth and other uncertainties in the forecasts are discussed in Appendix G.

3.1.2 Traffic Estimates

Application of the approach described above indicates that total aircraft activity in this country will almost double between 1968 and 1980, and more than double between 1980 and 1995, for a four-fold increase over-all.

Most aircraft flying in the 1990s are expected to be under some kind of control. To serve these users, the capacity of the en route IFR system will need to be increased by a factor of about eight. An equal number of VFR users may qualify for some kind of intermittent positive control in en route mixed airspace.

IFR operations at high density airports may at most triple. However, if it becomes necessary to provide ATC services to local and itinerant flights operating to and from all airports within approximately a 30-mile radius of a major terminal, tower (or computer) control loads may increase by a factor of 10 to 15 over today's peaks.

Aircraft Fleet Size

Numbers of aircraft in the combined air carrier, general aviation and military fleets will increase from 137 thousand in 1968 to 527 thousand in 1995. General aviation's proportion of total aircraft will increase from 84 percent, in 1968 to 95 percent in 1995 (3) (see Table 1).

TABLE 1.-*Aircraft fleet size*, 1968 to 1995.*

User category	1968	1980	1995
Air carrier	2, 452	3, 600	6, 700
General aviation	114, 186	214, 000	500, 000
Military	20, 000	20, 000	20, 000
All users	136, 638	237, 600	526, 700

* See Appendix G.

The 1995 air carrier fleet will be a mix of high capacity, short-haul aircraft, very likely including V/STOL type, large passenger and cargo transports, and SSTs. Although those aircraft will carry much larger payloads than now, they generally will cruise at subsonic speeds. It has been assumed that SSTs will operate at subsonic speeds over populated areas.

General aviation aircraft will operate in a manner similar to those flying today. New materials may be used, and more efficient engines introduced, but no revolutionary aircraft types are foreseen at this time. However, the proportion of turbine-powered and V/STOL aircraft will increase.

A military fleet of 20,000 aircraft was assumed through 1995 to reflect joint-use of the airspace by both civil and military users throughout the period. Piston aircraft mill be phased out of the inventory and replaced by turbine-powered conventional and V/STOL aircraft.

Flights

The flight, engine start to engine stop, is one basic measure of air traffic activity. Annual flights are forecast to increase from 36 million to 157 million between 1968 and 1995. About two-thirds of these flights will be itinerant and one-third local throughout the period (See Table 2).

Itinerant flights are further divided into IFR (instrument flight rules) and VFR (visual flight rules). Pilots of IFR aircraft must file an IFR flight plan with the air traffic control system; they are then provided separation from other IFR aircraft. Pilots of VFR aircraft may or may not file a flight plan which is used for flight following purposes. Airline and military pilots routinely file flight plans. An estimated 20 percent of general aviation pilots on itinerant flights file; of these, about one-third tile IFR and two-thirds VFR flight plans.

[3] General aviation aircraft now outnumber air carriers aircraft about 50 to 1. They fly almost four times as many hours as the air carriers, about twice as many miles, and generate about one-fifteenth as many passenger miles flown.

TABLE 2.-*Annual flights, 1968 to 1996* (in millions).

Aviation category	1968	1980	1995
Air carrier:			
Itinerant	5.2	9.8	14.1
Local	0.1	0.2	0.5
Total	5.3	10.0	14.6
General aviation:			
Itinerant	16.2	34.9	93.9
Local	8.7	16.5	43.3
Total	24.9	51.4	137.2
Military:			
Itinerant	2.2	1.7	1.5
Local	3.3	3.5	4.1
Total	5.5	5.2	5.6
All users:			
Itinerant	23.6	46.4	109.5
Local	12.1	20.2	47.9
Total	35.7	66.6	157.4

In fiscal year 1968, the air traffic control system handled some eight million IFR flights, seven million under air route traffic control center (ARTCC) control and one million under tower-to-tower en route control. IFR flights represented about one-third of itinerant flights that year, or between one-fourth and one-fifth of all flights.

Terminal Area Operations

Annual aircraft operations (4) are projected to increase four-fold between 1968 and 1995, from 128 million to 519 million (see Table 3).

TABLE 3.-*Annual operations, 1968 lo 1996 (in millions).*

User category	1968	1980	1995
Air carrier	11	21	31
General aviation	84	167	448
Military	33	34	40
All users	128	222	519

Approximately 40 percent of all operations will be conducted during itinerant flights, and approximately 60 percent during local flights. Pilots flying locally operate in the airport traffic pattern or within local practice areas in the vicinity of the airport; they often make more than one takeoff and landing during a single fight. Military local flying areas may extend 100 miles or more from the home base.

Only about two-fifths of all operations (53 million of the estimated 128 million) were conducted at FAA-tower airports in FY 1968. Military air bases accounted for one-fifth, and the remaining two-fifths took place at non-tower airports. As more towers are established, and as military activity declines relative to civil, the proportion of operations at FAA-tower airports will increase, representing perhaps three-fourths of the total by 1995.

[4] An aircraft operation is a take-off or landing.

Peak Minute Airborne Aircraft

An estimated 12,800 aircraft were airborne over the United States at the peak instant in 1968. By 1995, this number is expected to approximate 54,000 aircraft (see Table 4).

Of the 1995 total, 42,400 will be itinerant flights, and 12,000 local flights. Since approximately one-fourth of the total flight time of itinerant flights is spent traversing departure and arrival terminal areas, the total airborne load will be divided about equally between terminal and en route airspace.

ATC System Use

Participation in the air traffic control system in future years will be governed by regulations and the capacity of the system to accept controlled flights, as it is today. Regulations now stipulate, for example, that users of high-altitude airspace must file IFR flight plans; minimum equipment requirements also are specified. Pilots operating into and out of tower airports are required to maintain radio contact with the tower in the vicinity of the airport.

With regard to capacity limitations, indications are that participation in the en route IFR system would be greater today if all users could be accommodated without inconvenience or delay. The airlines prefer that all of their aircraft fly with separation protection, and 80 to 90 percent of their flights do so; airline jets are required to file IFR. The military have formalized an operational requirement for air traffic control of all flights, but only about one-half of their itinerant flights (including local jet training flights that penetrate high-altitude airspace) are now conducted under instrument flight rules. The filing of IFR flight plans by general aviation pilots is increasing rapidly, but in 1968, the level was still less than 10 percent of itinerant flights.

TABLE 4.- *Peak airborne aircraft, 1968 to 1996.*

User category	1968	1980	1995
Air carrier	1,300	2,100	4,600
General aviation	8,000	16,800	46,300
Military	3,500	3,300	3,500
All users	12,800	22,200	54,400

In summation, approximately one itinerant flight in three makes use of the IFR system today. A system that envisions imposing some degree of control on all aircraft would have to cope, not only with traffic growth, but also with the reservoir of flights that do not participate in the system now.

Estimating future ATC loads is complicated by our present inability to specify how much and what kind of control will be provided in various parts of the country, and to define exactly what we mean by "control." An uncontrolled flight operating in mixed airspace, for example, may be under intermittent positive control. It will impose a load on a computer, but not as great a load as an IFR flight since no flight planning will be required.

We can estimate the numbers of itinerant flights that might be full IFR if they could do so with no delay or restriction to their activity. For this purpose, the following assumptions with respect to itinerant flight activity in the post-1980 era were made :

Air carrier IFR.-100 percent of itinerant flights.

Military IFR-100 percent of itinerant flights plus 50 percent of jet aircraft local flights.

General aviation IFR-100 percent of turbine aircraft itinerant flights, 60 percent of multi-engine piston, and 5 percent of single-engine piston aircraft flights. No local or helicopter IFR flights. Note that if an IFR flight plan or the equivalent is required to fly in high-density terminal airspace, these general aviation percentages may increase. Also, as military helicopters fly IFR, so may general aviation.

Applying these assumptions yields the distribution of itinerant flight activity shown in Table 5 (en route control only; tower-controlled itinerant flights, approximately 15 percent of total IFR flights, included with "VFR, CVR or IPC") .

Thus we can expect a three-fold increase in IFR flights by 1980, and an eight-fold increase by 1995. In addition, by 1995 an equal number of VFR flights will be candidates for intermittent positive control. Peak ARTCC IFR loads may approximate 2000 simultaneously airborne aircraft, approximately eight times the peaks of today.

Estimating potential traffic loads in the terminal area is more complex. Peak controller loads today seldom exceed 10 airborne aircraft ; peak numbers of airborne aircraft under the control of a single radar terminal facility probably never exceed 30 or 40 aircraft, including IFR operations at satellite airports.

TABLE 5.—*Itinerant flights by flight rules,* 1968 to 1996 (*itinerant flights in millions*).

Flight Rules and Aviation Category	1968	1980	1995
Full IFR[1]	7.0	20.5	53.9
Air Carrier	4.3	9.8	14.1
General Aviation	1.2	8.2	37.5
Military	1.5	2.5	2.3
VFR, CVR, or IPC	17.3	26.7	56.4
Air Carrier	.9	—	—
General Aviation	15.0	26.7	56.4
Military	1.4	—	—
All Itinerant Flights	24.3	47.2	110.3
Air Carrier	5.2	9.8	14.1
General Aviation	16.2	34.9	93.9
Military	2.9	2.5	2.3

[1] Full IFR excludes IFR flights handled exclusively by tower-to-tower control, about 15 percent of total IFR flights today; these flights have been included with the "VFR (visual flight rule), CVR (controlled visual flight rule), or IPC (intermittent positive control)" category.

In the 1990s, IFR traffic loads at high-density towers may at most triple. Most operations at those locations are IFR today, and growth rates are constrained by airport capacity limitations. However, providing ATC services to local and itinerant flights operating to and from all airports within, say, a 30-mile radius of a major terminal would add a new dimension to terminal area control.

Many of these aircraft would receive at most intermittent positive control service, which would not add to controller workload. Also, aircraft practicing landings and takeoffs at nontower airports whose traffic patterns are below the line-of-sight of the surveillance aid, probably would get no service at all. Nevertheless, an increase of 10 to 15 times in the numbers of aircraft qualifying for some kind of terminal area ATC service can be expected between 1968 and 1995.

3.13 Delay

In recent years, the demand for air transportation has outstripped the provision of new facilities to handle it. Airport and airline operators have tried to cope with the growing imbalance between demand and capacity by improving airport and terminal facilities, introducing larger aircraft into the airline fleet, rescheduling to flatten peaks, padding schedules to absorb delays, and encouraging the diversion of general aviation aircraft operations to other airports. Business, commercial, and private aircraft operators operating into and out of major air traffic hubs have had to use less convenient airports or curtail their activities.

Despite the relief afforded by those measures, congestion at a few major airports today is such that users of the airports suffer costly penalties in the form of delay and inconvenience. Delays cost the airlines an estimated $I18 million in 1968, up 61 percent from the $73 million loss in 1967. Passenger inconvenience and loss of time may have cost an equal amount.

An airport is severely congested when peak hour delays exceed 30 to 60 minutes. Typical 'peak hour delays generally vary from 5 to 10 times the average delay for all operations throughout the year. On that basis, an average delay of 3 to 6 minutes per operation (or 30 minutes during peak periods) is the most that can be considered acceptable. It is unlikely that greater delays can be sustained without some diminution of demand.

Delays at four airports exceeded 3 minutes per operation in 1968 (Table 6) and at one, J. F. Kennedy International, they average 7.2 minutes per operation for the year.

Traffic queues build up very rapidly as the operations rate at an airport approaches capacity. During July 1968, delays at Kennedy average 14.2 minutes per operation, at an average cost of $6.54 per minute to the aircraft operators. Two-thirds of all flights were delayed, many for several hours. The delay per delayed aircraft averaged 21 minutes. Repercussions were felt throughout the country and overseas.

Fight restrictions have been invoked as a temporary expedient to speed traf%c flow at New York, Chicago, and Washington. But the rationing of flights is not a solution to the delay problem; it merely reduces delays for some at the expense of those who *can't* get a flight when they want it. Even without rationing, delays will build up only so far; the eventual consequences of inadequate airport/airspace capacity mill be a translation of delay costs into penalties ,associnted with unsatisfied demand for air transportation.

Congestion is a problem at major airports; w&her is a problem at all airports. Weather-induced delays often lead to flight diversions or cancellations. This is caused primarily by the lack of an all-weather landing system. Fewer than one-half of the airports in the country served by air carriers have any kind of instrument landing system, and only a handful of general aviation airports are so equipped.

TABLE *6.-Delays at four airports.*

Airport	average delay per operation in 19688 [1] minutes)
New York Kennedy	7.2
New York LaGuardia	4.8
Chicago O'Hare	3.8
Newark	3.4

[1] United Air Lines data.

Performance records for the certificated route air carriers show that approximately 5 percent of all scheduled flights (approximately 200,000 flights a year) are not completed for some reason. Data on general aviation performance are not available. Not all cancellations are attributable to Weather. Some are caused by mechanical problems with air craft, scheduling difficulties, and other factors. However, weather is thought to be responsible for more than one-half of the total. Weather-caused diversions are estimated to occur about one-fourth as often as cancellations. Weather also is a contributing cause in many approach and landing accidents. Costs to aircraft operators and passengers of weather-caused flight disruptions, including primary and secondary effects, amount to several hundred million dollars a year.

3.1.4 Safety

Historically, accident rates in civil aviation have trended downward more or less continuously. In terms of passenger fatalities per mile traveled, the safety record of the domestic scheduled airlines is now comparable with t.hose for buses and trains and considerably better than that for passenger automobiles and taxis. General aviation's record, while improving, is still seven or eight times higher than that for passenger cars when measured in terms of fatalities per passener mile[5]. Table 7 compares travel accident data.

Despite the continuing improvement in aviation accident rates, numbers of fatalities per year are increasing (Figure 1). A total of 1725 persons lost their lives in 1968,1374 in general aviation accidents and 351 in all operations of the U.S. certificated route and supplemental air carriers.

Accidents frequently result from the culmination of a number of small errors, each often unimportant in itself. Causes of accidents, therefore, are so diverse that they do not readily fall into discrete categories. The National Transportation

[5] NO singIe measure of accldrnt Or fatility rates 1s Satisactory for a11 purposes. Possenger fntalities per mile is readily understood nnd permits COmparisons among travel modes. However, some authors suggest that since most avlation accidents happen during takeoff or landing. accident rates should be based on number or nlrcroft departures. Others recommend the use of *an, exposure rate. i.e.. fatalities per passenger or per aircraft hour* flown. measured in terms of fatalities per aircraft hour flown air carrier and geneml nviation fatality rates areabout the same 40 and 55 fatalities per milllon flying hours In 1967, respectively.

TABLE 7.- *Comparable accidendata,* 1984 lo 87 *(Passenger' fatal&8 per lcw,Guo,mtI pluse?z~er mtles) .'*

Vehicle	1964	1965	1966	1967
Passenger automobiles and taxis:				
Total	2.40	2.50	2.40	2.40
Turnpike	1.20	1.20	1.30	1.10
Buses	0.15	0.16	0.20	0.20
Railroad passenger trains	0.05	0.07	0.16	0.09
Scheduled air transport planes	0.25	0.32	0.07	0.22
Domestic	0.14	0.38	0.09	0.29
International	0.63	0.12	0.00	0.00
General aviation:				
All (inc. crew)	26	[illegible]	[illegible]	[illegible]
Air taxi	10	[illegible]	[illegible]	[illegible]

[1] Source: Motor vehicle, bus, and domestic scheduled air transport data from the National Safety Council's "Accident Facts." General aviation accident data from the National Transportation Safety Board's "Annual Review of U.S. General Aviation Accidents;" passenger miles based on the average of 1.9 to 2.1 persons aboard aircraft in accidents, including pilot and crew. Air taxi estimates derived by method outlined in NTSB's "Analysis of Accidents Involving Air Taxi Operations, U.S. General Aviation, 1964-1966."

Safety Board cited the pilot as a factor in 37 percent of air carrier accidents in 1967, and in 82 percent of general aviation accidents.

About one-half of all accidents occur during the approach and landing phase of flight, suggesting a need for improved landing aids and perhaps for pilot education. In 1967, 31 of the 72 air carrier accidents and **3290** of the 6157 general aviation accidents occurred during landing or rollout

Although improved landing aids will not eliminate all landing accidents, they will reduce their probability, and the tradeoff potential is high. The average settlement for an accidental aviation death approximates $150,000; somewhat higher amounts have been detarmined for the present value of an individual's lifetime earning potential. Based on the $150,000 value, preventing a fatal accident in which 100 people were killed would save $150 million, or a sum sufficient to equip more than 100 runways with instrument landing systems.

Midair collisions are much less frequent, but usually more serious than landing accidents. General aviation aircraft were involved in 27 midair collisions in 1966, 25 in 1967, and 33 in 1968. Of these collisions, 57 percent were fatal. Two of the 1967 accidents 'were fatal collisions with air carrier aircraft-one near Urbana, Ohio, in which 26 people were killed, and the other near Hendersonville, North Carolina, in which 82 people died. In the latter accident, both aircraft were on IFR flight plans but not under radar control.

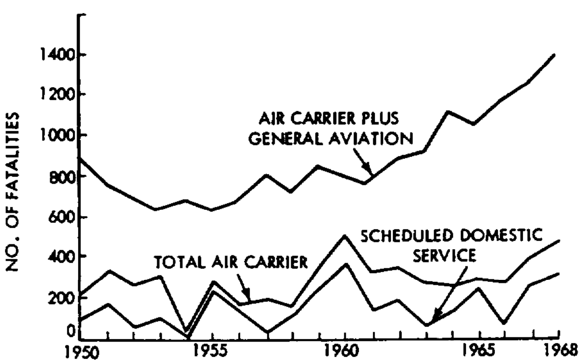


Figure **1.-Civil aviation fatalities, United** States **1950-1988.**

Weather is a contributing factor in about one out of three fatal general aviation accidents. Airframe, landing gear, powerplant, and flight system and instrument failures cause or contribute to about one of three air carrier accidents and one of six general aviation accidents. FAA personnel and facilities have compiled an outstanding record, being cited as a factor in less than one-half of 1 percent of all accidents in 1967.

Predicting future numbers of aviation fatalities is a precarious undertaking because of the infrequency with which accidents occur. The uncertainty is compounded by the fact that after the cause of an accident has been determined, steps are taken to prevent the recurrence of another from the same causal factors. If, however, we were to assume that, in the absence of corrective action and system improvements, observed 1964 to 1968 fatality rates would prevail through 1995, we could estimate total fatalities at that time @ (Table 8).

TABLE *8.-Aviation fotalities projected at 1964-68 fatality rates, 1970 to 1995*

Year	Air carrier (all operations)	General aviation (incl. crew)	Total
1964-68 average	281	1,173	1,454
1970	475	1,775	2,250
1975	800	2,550	3,350
1980	1350	4,000	5,350
1985	2100	5,500	7,600
1990	3400	7,800	11,200
1995	5100	11,300	16,400

[1] 1964-68 rates averaged about 0.3 air carrier fatalities per 100,000,000 passenger miles and 20 general aviation fatalities per 100,000,000 passenger (including crew) miles.

Today's accident rates in an environment with 10 to 12 times as much passenger travel probably would be unacceptable to many air travelers. A reasonable system goal might be a halving of the air transportation fatality rate every 10 or 15 years. This also seems an obtainable goal with

@Other things being equal, single-aircraft accidents mlght be expected to be directly proportional to air traffic activity, and mldalr collisions proportional to the square ot traffic density. For purposes of this dIscusslon, direct proportionality (constnnt fatality rate) has been assnmed.

closer monitoring of the flight naths of all aircraft. improved approach and landing aids, and what the National Transportation Safety Board calls a system safety approach to accident prevention.

3.2 THE AIRPORT SYSTEM

During the course of its study, the Committee becnme convinced that there were ways to increase airport terminal capacity in the near term and to increase operating rates by 40 percent, using existing equipment and standards. It was also concluded that the forecast increase in demand, twofold by 1980 and fourfold by 1995, can only be satisfied by (1) building new airports, (2) retrofitting major urban airports, and (3) accommodating V/STOL aircraft on special runways. No single technique will satisfy the demand.

The capacity increase at new and retrofitted airports could be achieved primarily by increasing runway utilization rates, reducing separations between aircraft in the approach and departure zones, and by closer spacing of parallel runways on the surface. The possibilities for accomplishing these changes have been analyzed and are discussed in this section.

A number of major airports have been examined as test cases. In these studies each airport was reconfigured and the resulting additional capacity computed. In one case- The John F. Kennedy Airport-the studies included layout of new route structures in order to investigate the effects of the increased capacity on neighboring airports and on the exposure of the nearby communities to aircraft noise.

These studies indicate that retrofitting can be used to greatly increase capacity. For example, in the case of JFK, the capacity was doubled while the increased noise exposure was actually reduced to below current levels.

The **Committee** is not proposing this capacity or design for Kennedy; it is not presuming to recommend any particular priorities concerning new air-Port construction as compared to retrofits of major urban terminals. The Committee is indicating that it is possible, at least in one case and probably in others, to increase airport capacity while decreasing noise exposure with the technology available today.[1] It should be kept in mind that these were not overall airport system studies. No attention was paid to problems such as access, terminal and parking expansion, or the need to maintain operation during retrofit.

Committee studies indicate that wake turbulence effects need not limit separations since procedures and perhaps suction devices that suck vortices off the runway can be effective. Safety of operation has been a paramount ground rule in all cases. The analyses of the safety aspects of the new procedures and technologies indiwto feasibility, but require further validation.

Although emphasis is placed on aircraft movements, it is recognized that the airport problem is considerably broader. Passenger facilities, parking, and airport access are a few of the other significant areas of concern, but are beyond the scope of this report and require analysis by the communities concerned.

321 The Present System

In order to identify system changes needed to increase airport capacity, it is important to understand those features of the present system that limit capacity. Table 9 identifies and examines specific elements of the present airport system that particularly influence capacity.

3.26 Increasing Airport Capacity

This section addresses the methodology for increasing the utility of airport acreage and the operational rates of runways.

Rwnway Design

The most critical factors with respect to increasing runway capacity are occupancy time and spacing. Runway occupancy time applies both to the time taken for arrival aircraft to clear the runway after touchdown and the time taken for a departure to taxi into place and proceed to liftoff. Therefore, the placement and design of exit and entry features are major design considerations. For mixed operations, runway occup.ancy time is especially critical. In the case of arrivals only, if spacing is reduced below present standards, occupancy time will become critical (Reference 2).

A large number of runway configurations have been suggested. These include straight, circular, V-type, driftoff, multiparallels, etc. Based on concrete requirements, capacity, safety for missed approaches, and utilization of land area, it appears that strsight and multiparallel concepts offer advantages over the others (Reference 3).

[1]There is little doubt that within the decade New York will require both a new major airport and increased capacity of its present airports.

TABLE Q.-Summary of airport capacity factors

Factor	Discussion
Separation standards:	
Minimum longitudinal spacing (arrival/arrival)	a. The present standard provides a minimum of 3 miles between IFR aircraft unless the tower has both aircraft in sight. This is the primary constraint on the present IFR arrival capacity.
Departure/arrival spacing	b. Present standards do not allow the release of a depratrure on the same runway or dependent runway if an arrival is within 2 miles of the threshold.
Departure/departure	c. Present standards prohibit successive departures within 60 seconds even when aircraft are flying divergent routes. Departures on parallel runways separated by 3500 feet or more on diverging courses can take off simultaneously if departure routes diverge by 45 degrees.
Independent parallels	d. Present standards require 5000 feet between parallels for simultaneous, independent IFR arrival operations. Except for simultaneous arrivals, operations are independent for 3500 feet or more. During VFR, independent operations are permitted down to 700-foot spacing.
Dependent parallels	e. Parallel spacing below 5000 feet, and not less than 3500 feet, can operate with dependent arrivals and with independent departures during IFR.
Offset parallels	f. Lateral separations for arrival/departure independent operations change at a rate of 100 feet for each 500-foot offset.
Rules and procedures—Ordering	a. Priority is given to arrivals over departures when conflicts occur. b. Present practice is to provide service on a first-come-first-served basis, modified at some airports that have quotas.
Control system delivery error to approach gate	a. The measure of effectiveness of an ATC final-spacing system is the precision with which it delivers aircraft to the approach gate. The smaller the error, the higher the landing rate. The final spacing system performance depends upon many factors. The most important are data acquisition system errors, control geometry and available airspace, aircraft speed errors, wind errors, communication delays, aircraft response to control commands, etc.
Aircraft performance—Variability in speed and runway occupancy.	a. The scheduled spacing between aircraft must be increased above the minimum allowable spacing in order to take into account variability in the expected speed and runway occupancy. This additional spacing or buffer time is a function of the percentage of time that minimum separations will be violated and the magnitude of the variability.
Geometry considerations:	
Location of ILS gate	a. The location of the outer marker affects the location of the gate, or point at which aircraft flying the final approach have a common path and cannot be altitude-separated. The longer the common path, the larger will be the landing interval when a slow aircraft follows a fast aircraft.
Runway layout	b. The capacity of an airport can be limited by many geometric factors. Such factors as runway orientation, spacing, intersection, length, exit locations, taxiways, crossover points, etc. can result in a less-than-ideal configuration, which in turn limits the capacity.
Environmental conditions:	
Winds and wind error	a. As headwinds increase, the ground speed decreases, and the landing intervals that are constrained by minimum distance-separation increase with a resultant reduction in landing rate. Wind error, the difference between forecast or measured wind and actual wind, can result in speed errors that affect the delivery error to the landing system and to the runway threshold.
Visibility	b. Poor visibility primarily reduces the VFR capacity. It naturally reduces the IFR capacity when the weather goes below airport minimums. Visibility also can affect airport surface movements.
Noise and airspace restrictions	c. Noise abatement procedures and other airspace restrictions affeet capacity adversely in that they restrict airspace utilization and runway utilization.
Wake turbulence	d. Appears to be a problem primarily between vehicles of widely varying size although the exact extent of this problem has not been defined clearly.
Runway surfaces	e. Slippery surfaces increase runway occupancy times.
Temperature.	f. High temperatures reduce the efficiency of jet engines and thus increase runway occupancy, with a possible reduction in departure capacity.
Landing aids—Instrument Landing System	a. Present ILS is affected by signal interference from aircraft overflying or blocking the localizer. For example, a departure overflying the localizer can cause serious interference to the localizer signal received by a landing aircraft. Similarly, an arrival can cause serious interference to the succeeding arrival.
Voice communications	In the present system, all air traffic control commands are relayed by voice communication. The Mode C transponder will reduce somewhat the pilot-to-controller communications but will not significantly reduce the controller-to-pilot communications.
Surface control	Relies primarily on visual observation and direct voice radio communications for navigation and control. During conditions of darkness, weather, or obstructed view, control is based on radio reports.

Figure 2 illustrates three basic types of runways :

1. Present conventional runway used for both arrival and departures with medium-speed turnoffs to the parallel taxiway.

2. Single runlyay with high-speed entrance and exist configurations permitting exit turns up to 60 knots and accelerated starts for departure.

3. Dual-lane runway, consisting of two close parallel runways (approximately 700 feet apart) that are dependent. The upper runway has high-speed turnoffs and is used for arrivals;the lower runway is for departures that can be released as arrivals touch down. Taxiing departures may cross the end of the arrival runway in groups interlaced between arrivals. For arrival rates in excess of approximately 60 per hour, it may be necessary to open an arrival gap every fern minutes for group crossings. In addition, either runway may be used for both arrivals and departures if one runway must be closed. For this reason, the departure runways should be provided with high-speed turnoffs so that they can effectively be used for arrivals in case the normal arrival runway is closed.

Single Runway Capacity

The runway system is most limited under IFR conditions; VFR. rates today are consistently higher than IFR. This stems mainly from the capability to reduce separations based on visual contact between aircraft. Airports use IFR separations, with a corresponding reduction in operation rate, when ceilings are less than 1000 feet, and visibility less than 3 miles.

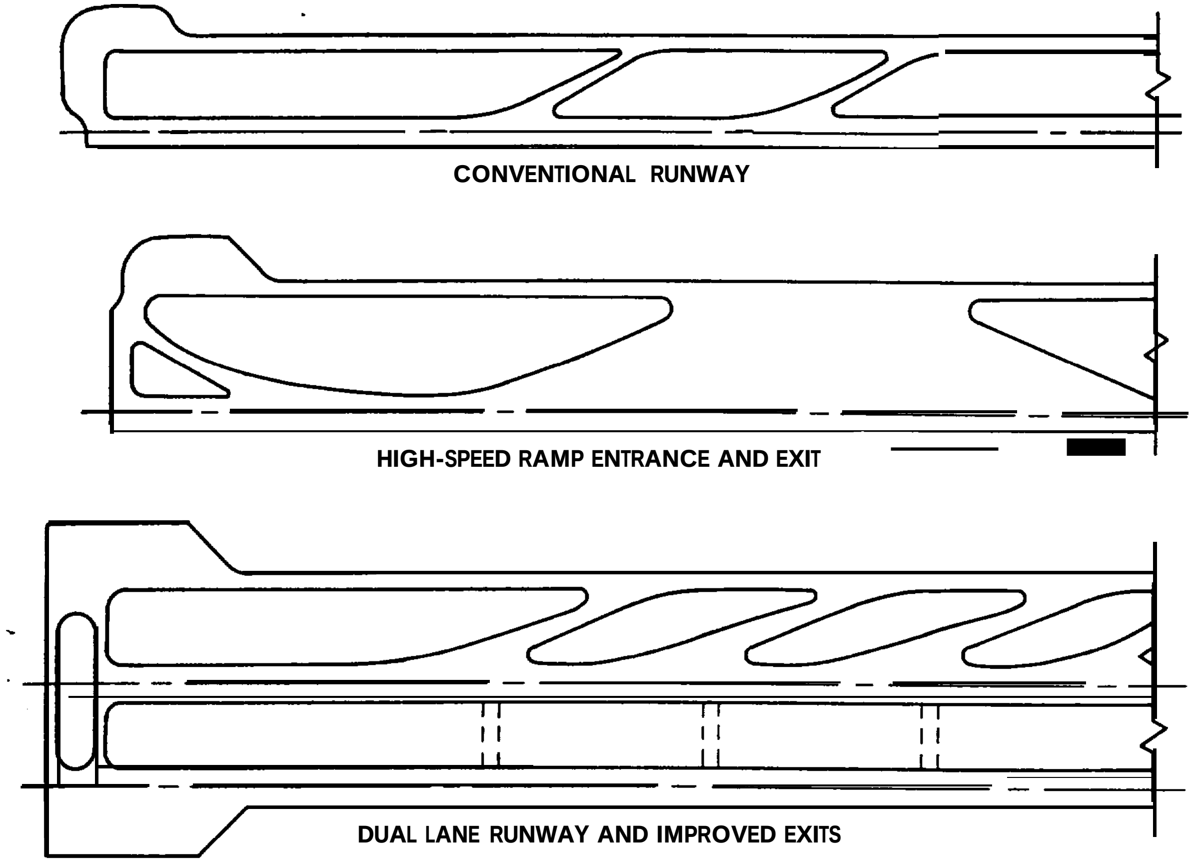


Figure 2-Runway configurations.

Table **10** illustrates the IFR capacity of the three runway geometries described in Figure 2 based on various levels of automation and longitudinal separation criteria (References 4, 5, and 6). The **horizontal** arrow (A) illustrates the near-term **capacity increases,** using additional pavement with **no** change in the level of automation or **separation.** The two vertical arrows on the right **side, (B)** and (C), show the results of automation **and** separation changes respectively.

The automation and procedural alternatives **listed in Table** 9 are as follows :

1(a) The capacities listed in this case are derived from actual observations of present operations. The standards used today require a 3-mile minimum separation between successive arrivals and a 2-mile minimum between a departure and the following arrival. The separations are determined by a controller's visual interpretation of relative positions when using a display. Thus, the actual interval may sometimes be less, leading to a higher arrival rate for the empirical results as compared to the computer-derived results of 1 (b).

1 (b) Similar standards as listed in 1 (a) are applied. The listed capacities are computed, using a model adhering to IFR separation standards. The computed mised capacity is higher than the observed mixed capacity since, in the computer case, it was assumed that arrivals and departures are interleaved on a one-for-one basis.

2. The standards are the same as 1 (b) and a computer-aided approach spacing is provided to the controller. The present surveillance tracking system is used. The control system is assumed to deliver aircraft to the runway threshold with an accuracy of 11 seconds (1 sigma).

3. Similar conditions to 2 exist and a command control spacing function is added with a data link between the computer and aircraft to provide more direct control. The error in delivery to the approach gate is reduced to 5 seconds **(1** sigma), and some degree of speed segregation of aircraft is assumed.

4. Similar conditions to 3 exist with the exception that the spacing between successive arrivals is reduced to 2 miles.

TABLE 10.—*Single runway IFR capacities.*

(A) Additional pavement

Automation and procedural alternatives	Type operation	Runway design alternatives		
		Current layout 	Improved exits/ entrance 	Dual-lane runway 
		Operations per hour		
1(a) . Present standards . Manual operation . Empirical based	Arrivals Mixed	38 50	42 55	42 70
1(b) . Present standards . Manual operations . Computed	Arrivals Mixed	35 59	35 64	35 71
2 . Computer-aided approach spacing . σ=11 sec . 3-mile spacing	Arrivals Mixed	41 65	41 72	41 82
3 . Command control spacing (CCS) . Speed class sequencing . Speed segregation . σ=5 sec . 3-mile spacing	Arrivals Mixed	48 69	48 77	48 95
4 . Same as 3 but with 2-mile spacing	Arrivals Mixed		68 78	68 129
5 . Same as 4 but with departure/arrival interval of 40 sec. average	Arrivals Mixed		68 85	68 132

(B) Increasing automation

(C) Automation and reduced

5. The same conditions as indicated in 4 exist with the exception that the departure followed by arrival threshold is reduced to an average of 40 seconds.

The major assumptions in deriving Table 10 are as follows :

1. A 6-mile gate was used.
2. No wind effects were assumed.
3. Aircraft approach speed mix was 20 percent at 120 knots, 20 percent at 135 knots, and 60 percent at 150 knots.
4. With the exception of alternative 1(a) in the table, the interleaved arrivals and departures are on a one-for-one basis.
5. Runway occupancy time was based on a 1500-foot touchdown point and runway deceleration of 6 feet/sec, plus a 6-second safety factor.
6. For 3-mile separation, a 95 percent confidence level was assumed at 2.5 miles or greater separation. For a 2-mile spacing, a 99-percent confidence level was assumed at 1.5 miles or greater separation.
7. For alternatives 1(b) to 4, the interval between a departure and ensuing arrival is 2 miles (with a confidence level of 95 percent at spacings of 1.5 miles or greater for the current layout and 90 percent for the improved layouts). For alternative 5, a 40-second average was used directly.

The following conclusions are obtained from Table 10 :

1. The present runway layout appears limited to a 38 percent increase in IFR capacity utilizing a high level of automation involving upgraded ground and airborne equipment. A 40 percent increase can be obtained by using the dual-lane runway concept and retaining the present standards and operating procedures. It is likely that it mill take longer to achieve increased levels of automation, which requires both ground and airborne modifications, than it will to provide the additional pavement. The benefit derived from each approach is nearly equal.

2. A 64-percent increase in IFR capacity can be obtained by using the dual-lane runway, computer-aided approach spacing, and the use of present standards and procedures. This is approximately the same increase that would be obtained by adding high-speed exits and entrances to the present runway, a high level of automation, and a reduction in separation standards.

3. An increase in IFR capacity approach' 165 percent may be feasible with the dual-lane

runway, a high level of automation, a reasonable reduction in separation standards, and an appropriate change in procedures. realtime simulations confirmed the capacity of the dual-runway configurations operated with the various levels of automation and with the suggested changes in separation (Reference 7).

The accuracy of aircraft delivery to the runway threshold can be computed by determining (1) the accuracy with which the aircraft can be delivered to the approach gate and (2) the accuracy with which the aircraft can complete the final approach in a given time period. A time-to-turn control concept is a terminal control strategy that seems capable of high delivery accuracy to the approach gate (Reference 8). The geometry of the time-to-turn concept is illustrated in Figure 3. A sensitivity analysis has shown that aircraft can be delivered to the approach gate with a 5-second **(1-sigma)** accuracy provided that the surveillance system **has** an error of less than $\frac{1}{10}$ mile, the heading error **is** less than 5 degrees, the mind error is less than 5 knots, and the aircraft speed error is less than 5 knots. The effect of these errors is shown in Figure 4 (Reference 9). Beyond the approach gate, the pilot must meet the desired

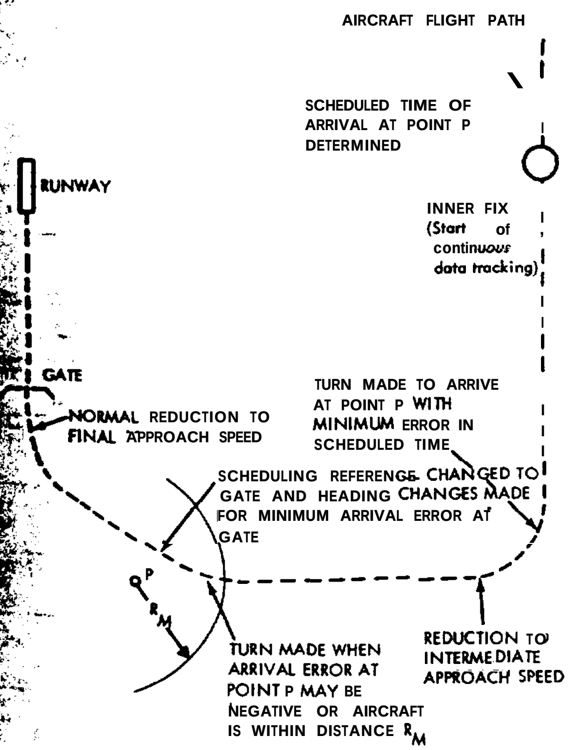


FIGURE 3.-Typical time-to-turn approach geometry.

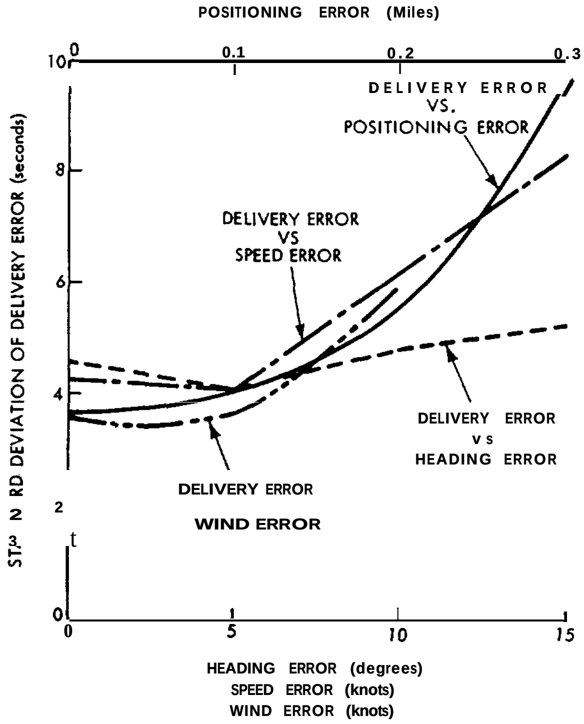


FIGURE 4--Sensitivity of delivery error at approach gate to Positioning, heading. speed, and wind errors.

time of arrival at runway threshold by maintaining his desired linal approach speed. The errors in delivery time using various speed sensors are shown in Table 11.

The error in delivery to the approach gate is added (rms) to the error in transit time between the approach gate and the runway threshold. The total error in aircraft delivery can be reduced by

TABLE II.--Error in transit time *between outer marker and runway threshold* in seconds (f u).

Technique	Manual		Autothrottle	
	Still Air	Wind-shear	Still air	Wind-shear
Pilot-static airspeed (no wind conditions)	3.89	....	3.21	....
Pilot-static airspeed (including wind variation)	. . .	5.25	....	3.72
Doppler ground speed	2.39	4.21	1.19	2.10
Inertial ground speed	3.54	4.95	2.87	3.36
DME ground speed	3.02	4.6	1.82	2.52
DME distance	5.2	6.25	3.56	3.96
Precision DME	3.12	4.66	1.56	2.33

=-80-'1L3

these techniques to approximately 5 seconds (1 sigma) from the current arrival error of approximately 30 seconds.

Multirunway Capacity

Using Table 10 data for single runway hourly operational rates, it can be shown that multiple parallel runways can achieve corresponding increases tempered by effects of taxiway crossings and relative location of terminal facilities. Table 12, for illustration purposes, shows two configurations of runway/terminal relationships and provides achievable rates based on a sampling of the criteria used in Table 10. This table does reflect some tradeoff of capacity for compromises in airspace control, particularly for the four parallels where it can be expected that marshalling traffic from transition to the terminal area will not be ideal. This table lists the anticipated increases in IFR multirunway capacity for two runway configurations. In the first configuration, where the terminal is located between two independent runways, capacities are estimated for both the improved high-speed exits and entrances on the present type of runway and the dual-lane runway concepts. In the second, where four independent runways are used, it is assumed that the terminals are located between the runways, all runways are dual-lane, and some ground traffic crossings of runways may be required. The procedural alternatives are the same as for Table 10, with the exception that alternatives 1 (a) and 4 are not listed. The major assumptions are also the same.

The data in Table 12 have the following significance:

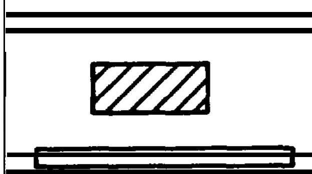
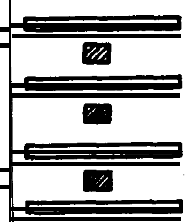
1. Considerable capacity increases are feasible well beyond current peak IFR rates in major hub airports that currently achieve peaks of approximately 100 operations per hour. An increase of approximately 390 percent in IFR capacity can be obtained if an existing two-independent-runway layout is expanded to a four-independent, dual-lane runway configuration that uses a high level of automation and reduced separation standards.

2. Optimum location of multiple, parallel dual-lane runways with respect to terminal facilities is highly desirable for maximum utilization of potential runway capacity, particularly under reduced separation criteria.

The Final Approach and Departure Zone

The terminal airspace must have a capacity and configuration that matches the runway designs described in the preceding pages. This section addresses the terminal airspace volume from the runways to the transition zone in which traffic is under the cognizance of the terminal ares traffic system. To further bound the scope of this section, the traffic control functions of marshalling, sequencing, and monitoring for conflicts are discussed in Section 3.4.

TABLE 12.-IFR capacities, parallel runways.

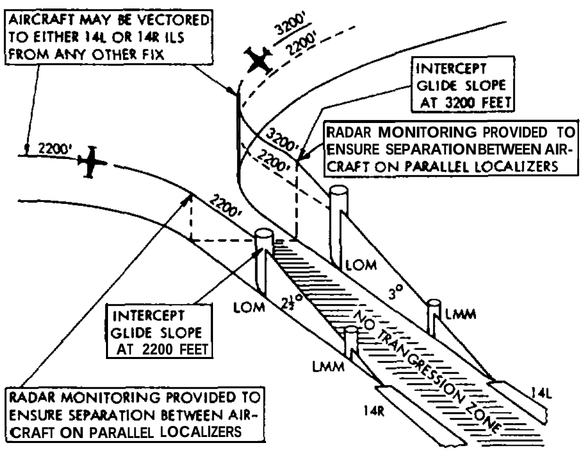
Automation and procedural alternatives	Type operation	Terminal between  Independent runways		4 Ind. runways 
		Impr. exit runways	Dual-lane runways	Dual lane
1(b) . Modified present standards . Manual operations . Computed	Arrivals Mixed	70 128	70 142	120 240
2 . Computer-aided approach spacing . σ=11 sec . 3-mile spacing	Arrivals Mixed	82 144	82 164	144 288
3 . Command control spacing . Speed class sequencing . Speed segregation . σ=5 sec . 3-mile spacing	Arrivals Mixed	96 154	96 190	172 344
5 . Same as 3 but with departure/arrival interval of 40 sec. average . 2-mile spacing	Arrivals Mixed	136 170	136 264	250 500

Reduced runway separation and increased capacity are reflected in a reduction of the longitudinal and lateral separations during approach and departure. This section considers the environmental, flight control aerodynamic, and guidance factors that determine allowable airspace separation.

Reduced Lateral Separation

The criteria for current operations to parallel runways under JFR conditions were defined in Table 9. Since independent parallel operations offer the greatest operational flexibility, this discussion deals mainly with the possibility of reducing the 5000-foot minimum separation in current use (Reference 10). This type of operation is authorized at the Chicago O'Hare Airport and Los Angeles International Airport. The vast majority of U.S. airports have parallel runways that do not meet this 5000-foot spacing requirement; moreover, the cost of land acquisition to meet this requirement is generally prohibitive.

Figure 5 illustrates the geometry of a current parallel operation. Considerable data are available from past tests and studies on similar operations. This provides an estimate of the deviation from flight path because of guidance, flight control, and environmental effects. The first few moments of the error distributions can be identified for each of the critical effects contributing to flight-path deviation. However, there is uncertainty with respect to the higher-order moments, or the "tails" of the error distributions. If a completely independent surveillance system detected deviations and potential conflicts and directed timely corrective action, the "tails" of the error distribution tend to become truncated. The accuracy and



hQWE J.-Current parallel approach operation.

data rate requirements of such a surveillance system are discussed in Section 3.4. The dependence of the surveillance system alarm on deviation, cross track velocity, and occupancy of the neighboring approach track and the manner of communication to the cockpit of the ground-derived alarm has not been treated in detail by the Committee. It was assumed that the surveillance system alters the tails of the distribution sufficiently to permit the use of an untruncnted Gaussian distribution in a calculation of risk probabilities. To assess the risk level implied by closer lateral separations, a mathematical model was developed expressing probability of collision of aircraft on parallel final approach tracks (Reference 11). The model was a Gaussian distribution with untruncated tails which seems to be a conservative assumption when a surveillance system is actually available to call for a missed approach. The following major conditions were applied to the model :

Duration of Flight-200 seconds
Aircraft Longitudinal Spacing-2 miles
Aircraft Dimensions-150 feet long, 150-foot wing span
One-Sigma Cross Track Error-300 feet

The resultant approximate collision probabilities for this set of conditions are:

Risk of Collision	separation (feet)
10^{-7}	2400
10^{-8}	2.550
10^{-9}	2700
10^{-10}	2900

This risk calculation is part of the basis for recommending the decrease in IFR runway separation standards. It should be further substantiated by flight evaluation and simulation involving biased sampling and adjoint Monte Carlo techniques.

In the region of flight between the departure or approach course and the en route course, separations increase from that of the parallel runway spacing to the 2-mile route width expected between tracks using the short distance navigation aid. In this region, the scanning-beam microwave ILS provides position information to the aircraft. Therefore, the aircraft can navigate on curved flight paths connecting the en route course to the runways. Such precision curved paths provide better sequencing flexibility from the en route course to the runway, more asymptotic intercepts of the approach and landing course, and routings to avoid noise-sensitive areas.

Reduced Longitudinal Separation

Runway acceptance rates have been shown to be sensitive to both separation and accuracy of delivery to an approach gate. Assuming that ATC feeds aircraft to the final approach zone, and that their relative speeds to that safe separation are dynamically achievable, the longitudinal problem is to continue to maintain safe separation and to achieve the scheduled arrival time over threshold (and clear of runway).

The probability of overtake was modeled assuming that, at the start of final approach, spacing has been adjusted to compensate for differences in aircraft velocities on final approach (Reference 12). Thus, the situation can be treated as if all aircraft have the same mean velocity on final approach. As in the case of the lateral separation problem, the first few moments of the velocity error-density function are understood far better than the higher momenta The probability of collision because of overtake at the reduced longitudinal separation suggested for increasing capacity is extremely small, even in the absence of surveillance, if aircraft are properly spaced initially. The current surveillance system in capable of determining when an overtake might occur with sufficient accuracy and in sufficient time so that an approach waveoff can be commanded in a timely way to the overtaking aircraft. Thus, the probability of collision because of overtake with even crude surveillance becomes essentially zero.

However, waveoffs to avoid simultaneous runway occupancy may increase as separations are reduced. The terminal control system may be prevented from requiring speed adjustments on final approach. In this case, the accuracy of delivery to the approach gate and the scheduled accuracy with which the pilot can achieve the final approach determines the waveoff rate for a given runway operating rate

If it is assumed, because of runway occupancy limitation, that the minimum spacing between aircraft can be no less than 40 seconds, then any time-separation on final approach less than this becomes the criterion for ordering an approach waveoff. Other waveoff criteria should be investigated based on a combination of some minimum distance or time and relative velocity. Current runway occupancy time varies from 50 to 70 seconds. However, this is in the absence of any special pressures or facilities to expedite runway exit.

Let us assume that the common approach path is 10 miles long, the accuracy of delivery to the approach gate is 5 seconds, the nominal aircraft speed on final is 150 knots, and the standard deviation of relat.ive velocity between two aircraft, each of which is flying its predicted approach speed, is 5 knots. Then, the average spacing at the threshold of the runway must be approximately 60 seconds for a waveoff probability of 0.001, even though the criterion for a waveoff is 40 seconds (References 2 and 11). The 60-second spacing corresponds to a 2 1/2-mile separation in this case. Figure 6 summirizes the relationship between probability of waveoff and runway operating rate for various maximum runway occupancy times as a function of the time-accuracy with which aircraft can accomplish the entire approach to runway threshold.

The average spacing of 60 seconds is increased or decreased at the approach gate depending on the desired approach speed of each aircraft. For a slow aircraft following a fast aircraft, this time-separation is decreased. For a fast aircraft following a slow aircraft, the time-separation at the approach gate is increased.

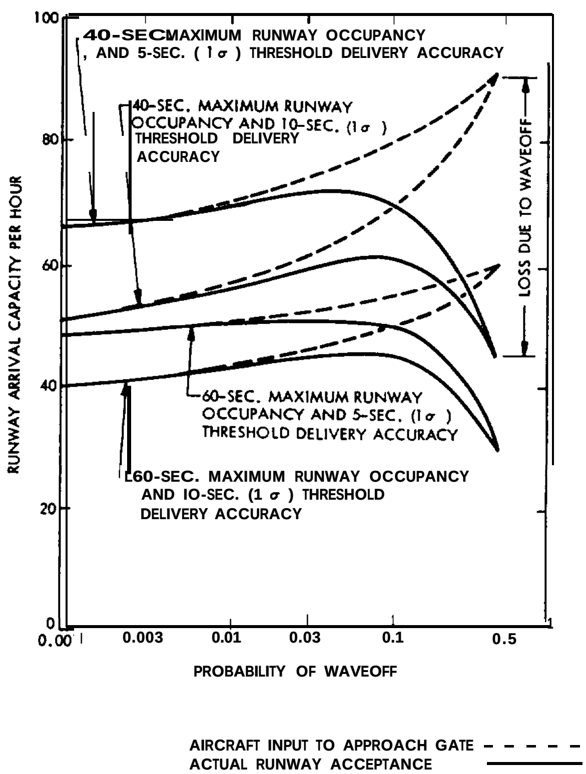


FIGURE &-Probability of approach waveoff vs runway arrival capacity for several runway occupancy times nnd delivery accuracies to runway threshold.

In order to achieve a nominal separation of 2 miles, as compared to the 2 1/2, miles inthe example of the previous paragraph, it seems necessary that the surveillance system indicate small speed adjustments for aircraft during the initial portion of their final approach. For a 5-mile final approach, these speed adjustments will be less than 10 knots.

ILS Localizer Interference Effect on Longitudinal Spacing

An aircraft in the vicinity of the ILS localizer can cause a reflected signal to be transmitted to an approaching aircraft. The reflected signal can be of sufficient magnitude to cause large net errors to the localizer course line for several seconds duration. This effect is commonly called "overflight interference."

Analyses conducted in this country and abroad have concluded that this problem precludes the possibility of reducing arrival separations below 3 miles (Reference 13). There is also a question with respect to continuing present 2-mile separations between departures and arrivals, particularly in Category I weather or worse. Furthermore, there are some who believe that this problem constitutes a hazard for Category III operations. No corrective solution has been found to remove this effect. Possibilities such as inertial augmentation or the use of dual localizers, one at each runway end (downwind localizer) , have been suggested, but are stop-gap measures at best.

A new landing aid will be required to overcome this problem, which is one of many major constraints of the current ILS system. The microwave ILS solves this problem.

3.2.3 High-Capacity Airport Design

As indicated earlier, multirunway configurations are required to have capacities exceeding 50 IFR mixed operations per hour when a single, active runway is used in the present system. This limitation is raised to approximately 130 operations per hour with a dual-lane runway, a high level of automation, and reduced separation. To go beyond this capacity, parallel dual-lane runways are required.

When more than one runway exists on an airport, building locations are vital and integral considerations in design and use of the runway-taxiway-apron complex. Passenger terminal facilities for a super airport of tomorrow, which is planned to handle approximately 500 hourly operations, Will require 300 aircraft gates over an area of approximately 2 square miles. Other areas to accommodate aircraft maintenance, cargo, general aviation, or even satellite passenger terminal support will add to the total space requirements

Closer spacing of IFR arrival runways is needed not only to assist existing airports that have serious expansion problems at the 5000 to 6000-foot spacing, but also to permit logical and economical expansion of new airports. If simultaneous IFR approaches can be made at the 2500-foot spacing, a considerable reduction in land requirements and cost is feasible. Most large terminal designs for passengers require spacings up to 6000 feet between parallel runways on esch side of the terminal in order to provide sufficient areas for taxiways, high-speed turnoffs, ramps, and gates. Some reduction is possible for the smaller terminals used for V/STOL, air taxi, and general aviation. However, reduction in runway separation below approximately 2500 feet presents problems in land use between the runways At a separation of 2000 feet, for example, not enough room exists between runways to do much more than park or taxi aircraft. No major building facilities could be constructed within the 2000-foot area if taxiway, ramp, aircraft parking, roads, and automobile parking are required.

The "convenient runway" idea becomes extremely important when dealing with large airport areas. The split or multiterminal concept will be greatly facilitated by establishing flight plans from airport runway to airport runway rather than simply airport to airport. Runway crossing problems could be reduced greatly, taxiing flow improved, and taxi lengths reduced if, for example, cargo aircraft were assigned to the runway most convenient to the cargo terminal. This type of sophist&ted system will require scheduling relinements by the airlines and ATC procedural action.

Crosswind runways are not only expensive to construct, but act to constrain growth of an airport. Building accessibility is greatly hampered, costs of overpasses are extreme, runway use and location of navigational aids is difficult, etc. Since the demand for the secondary direction is the key to providing runways in this direction, technical efforts directed toward reducing the aircraft limitations should be increased. Fox example, at a typical location with a crosswind component of 15 to 20 knots, the annual use of a crosswind runway direction could be on the order of 8 to 10 percent, but if satisfactory operational crosswind capability of the aircraft were improved to sn average of

35 to 50 knots, utilization of the secondary direction would decrease to lees than 1 percent. At most locations, crosswind runways can be limited in capacity because of their low utilization.

Handling of V/STOL aircraft so that these air-c.raft are compatible in a complex overall terminal environment is essential to planning for major airports. If on-airport operations are required, a separate runway appears to be desirable for V/STOL to operate most efficiently. Some reduction in effectiveness may occur if separate and unnpatible aircraft-handling techniques cannot be developed in a saturated IFR condition. If the V/STOL and conventional type of aircraft require considerable interchange of passengers, baggage, and cargo, either the operations must be integrated or a high-speed exchange between terminals must be provided. The V/STOL must be operated on either a close, separate runway or a distant runway with high-speed ground connections.

It has been suggested that general aviation airports be established separately from air carrier airports in order to reduce the traffic demand and to segregate classes of aircraft with different performance characteristics. Under a typical mix of large, medium, and small aircraft, if general aviation aircraft are removed from the airport, the actual number of opentions per hour decreases. However, the total number of air carrier operations increases As a result, total passenger-carrying capacity for a single runway would be substantially greater if small aircraft can be handled on separate runways.

Under today's operating conditions, smaller aircraft can use shorter final approaches and lower runway occupancy times. These two factors help today's mixed operations show higher capacities than when air carrier airplanes are operating alone. However, to achieve the runway capacities hoped for in the future, more precise spacing, sequencing, and lower runway occupancy times will be necessary. Uniform approach speeds will be needed to assure precise spacing and sequencing. The use of high-speed exits will be necessary to reduce runway occupancy time to desired levels Accordingly, a mix of small and large aircraft will no longer increase hourly aircraft capacity but will degrade it.

At the higher capacity airports where facilities for general aviation are required to meat user demands, separate runways and terminal areas with high-speed ground transportation appear to be a good solution. However, wherever possible, separate airports should be provided for general aviation users who do not require connections with air carriers.

Preliminary Test of a High-Capacity Retrofit

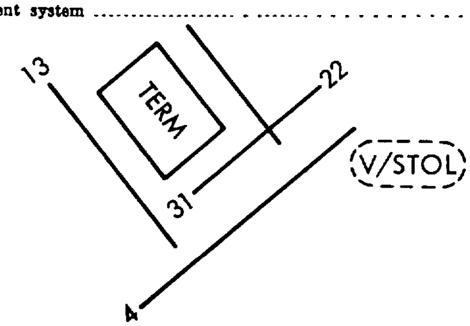
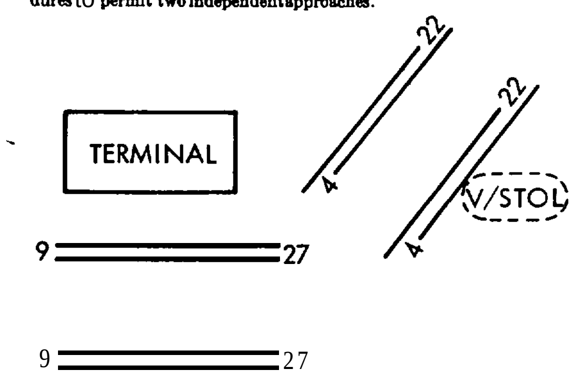
A limited study was conducted on the John F. Kennedy International Airport in order to determine the effects of the increased capacity concepts, discussed earlier, on a major terminal (Reference 4). In addition, the noise contours were computed for one realignment of the runways and associated arrival and departure routes (Reference 14). The results indicated that major increases in capacity could be obtained by the use of dual-lane runways, curved approach and departure routes, and close, parallel runways with independent approaches. This new runway configuration also provided a reduction in the area and number of people exposed to aircraft noise.

Table 13 lists (A) the present system, (B) the proposed new runway configuration with four dual-lane runways and modified procedures to permit two independent approaches, and (C) the effect of future automation and reduced separation. In example (B), capacity is increased approximately 80 percent, maintaining the present 3-mile longitudinal spacing; however, a reduction in the present lateral spacing to approximately 2500 feet is assumed. This design is predicted on the use of a scanning-beam microwave ILS and an improved data acquisition system. Implementation of these improvements is estimated for the 1975 1980 period. In (C) , capacity is increased by 200 percent by adding a higher level of automated control and reducing the separation standards.

Noise Analysis of the Retrofit

In 1968, there were approximately 450,000 total aircraft operations at JFK that exposed 100 square miles and 750,000 people to aircraft noise at levels of annoyance ranging from individual dislike to concerted group action against the air commerce industry (corresponding to a Noise Exposure Forecast, NEF, of 30). By reconfiguring runways, relocating arrival and departure paths, establishing 'new standards for lateral and longitudinal separation, reducing thrust at 3.5 nautical miles from brake release, and retrofitting only four engine turbofans with acoustically treated nacelles, it is possible to increase the number of operations to 1 million per year while "rolling-back" the land exposed to this level of noise to 36 square miles containing 500,000 people.

TABLE 13.-Capacity *at JFK airport.*

Capacity improvement	Approximate IFR hourly capacity	Cost ($ million)	Remarks
A. Present system 	70 to 80	....	Present IF-R capacity is 70 to 80/hr. when arrivals equal departures. During peak afternoon hours, arrival demand is 20 to 7% more than depar-turn. With one arrival runway, this Imbalance reduces capacity by about 10 operations/hr. The trend to reduce gate occupancy suggests that in the future it is reasonable to r,simma that arrivals will equal departareS over a period of
B. New runway configuration with four dual-lane runways and modified procedures tO permit two independent approaches. 	120 to 140	200 to 300	Offset thresholds of dual-lane runways in 4/22 direction are recommended for noise abatement, and use of inboard threshold for arrivals reduces capacity when 4/22 direction alone is in use. The 9/27 direction can be used for about 12% of the total of 13% actual IFR weather. Best-use configurations are 4/27 and 22/27 and could be used a total of 5% of the actual IFR weather.
C. Same configuration as B with automated control providing 40-second interval between dependent arrivals and departures, 1-sigma deviation of 5 seconds with 2-mile separation for arrivals.	200 to 200	no to 300	No automation costs are included. The effects of runway direction as similar to the remarks under B.

The new runway configuration consists of eliminating the existing 13/31 runways, locating a pair of 9/27 dual runways south of the existing 13L/31R runway, and locating a pair of 4/22 dual runways on the existing 4/22 runways. The 4/22's are staggered longitudinally for noise abatement purposes. Approach and departure paths would be as close to the airport as practical so as to be over water or sparsely populated areas. advantage is taken of the topographic and demographic characteristics of the Jamaica Bay area near the airport. Figure 7 shows the relocated runways and flight paths.

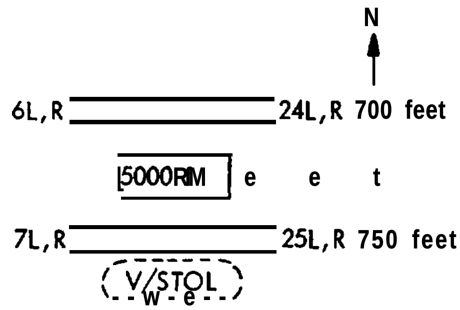
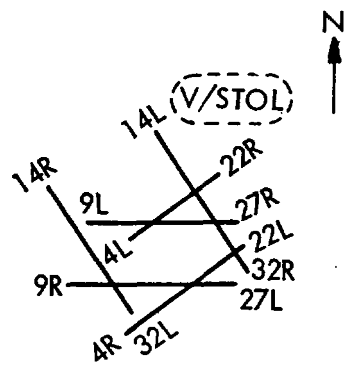
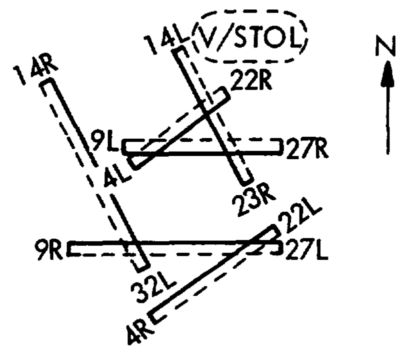
The results of the methodology as applied to JFK are shown in Table 14. A comparison of selected parameters for the two airport designs is shown in Table 15.

For VFR conditions (87 percent of the time), the arrival and departure paths were located over water until relatively close to the airport. For IFR conditions (13 percent of the time), conventional a-degree ILS approaches were used for arrivals. In addition, two curving 1/2-degree-per-second rate of turn, Canarsie-type approaches were selected ; IFR departures used the same paths as VFR departures.

Aircraft were separated into eight classes of 2/3/4 engine turbojets, turbofans, jumbos, airbuses, both standard and stretched versions. Takeoff gross weights were obtained from a separate analysis of trip lengths of forecast departures. Gross weight is significant since it is an indication of the departure profile and hence the noise heard on the ground at a given location.

Assignment of runway and flight path utilization was made on the basis of recorded wind rose data. Figure 8 shows the percentage of runway utilization for arrivals and departures. The summer wind rose is evidently such that there are more arrivals from the northeast and fewer from the

TABLE 16.—*Capacity increase examples.*

Location	Description of capacity improvement	Approximate IFR hourly capacity	Cost ($ million)	Remarks
LAX	A. No change.  	140		New runway 6/24 now under construction is assumed completed and in operation in capacity figures shown. No cost indicated since the four parallel runways are all in accordance with the current layout plans.
	B. Same layout as A, but assume CCS, $\sigma=5$ sec., 2-mile spacing, speed segregation by runway.	210		Same remarks as A; cost of technological developments not known.
ORD	A. No change.  	130 to 95		New runway 4R/22L is assumed completed and in operation in capacity figures shown.
	B. Same as A, but widen each conventional runway to a "dual-lane" runway  	160 to 120	50	Cost of widening to "dual-lane" includes associated taxiways, lighting, etc. Approximately $800/LF used as basis for estimating. The maximum figure represents "best" use of favorable intersections with parallels, such as 27R, L–32R–22L. The lower figure represents use of parallel, dual-lane runways only, such as 14R, L.
	C. Same as B, but assume CCS, $\sigma=5$ sec.; 2 mile spacing; speed segregation	270 to 210	50	Cost of automation is not included.

:marks

: now under construc- d completed and in pacity figures shown. :d since the four paral- oil in accordance with out plans.

A; cost of technologi- :s not known.

22L is assumed com- operation in capacity

: to "dual-lane" in- d taxiways, lighting, :ely $800/LF used as ting. The maximum "best" use of favor- s with parallels, such 2L. The lower figure of parallel, dual-lane ich as 14R, L.

n is not included.

TABLE 16.—*Capacity increase examples*—Continued.

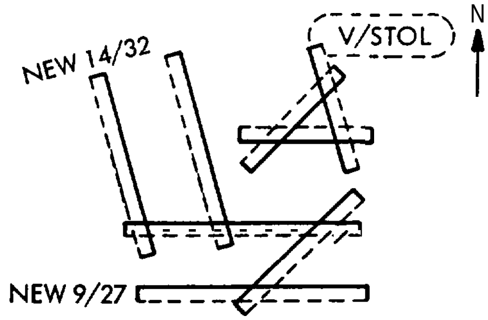
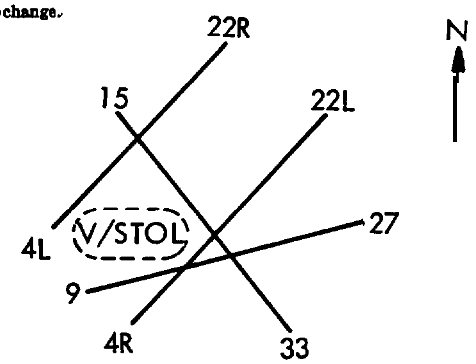
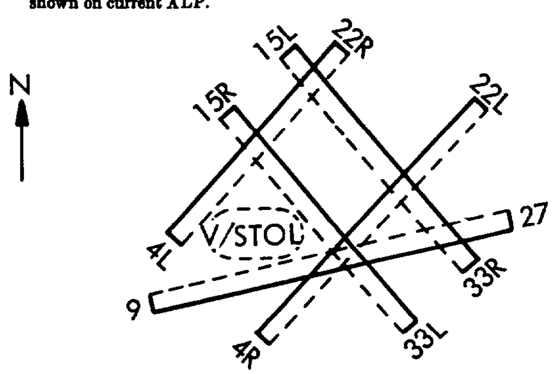
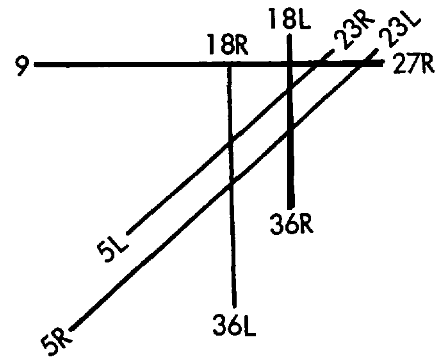
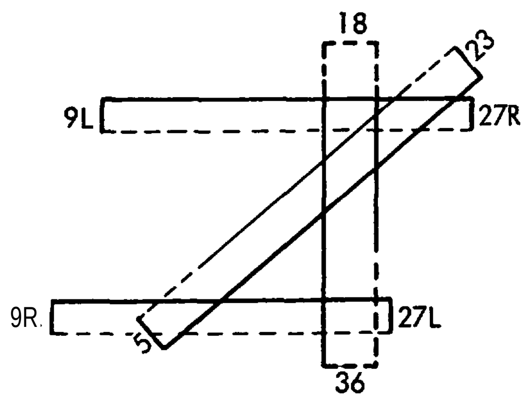
Location	Description of capacity improvement	Approximate IFR hourly capacity	Cost ($ million)	Remarks
	D. Same as C, but add a third, parallel "dual-lane" runway in the 14/32 and 9/27 directions, outboard of present parallels at 3500-foot separation. 	300 to 210*	140	Assume three simultaneous arrival courses permitted and lateral spacing of 3500 feet for simultaneous arrivals allowable. Also assume new cargo or other terminal facilities would be built within both new 3500-foot areas. *A capacity of 210 would occur less than 1% of the time since three runways are available for more than 99% of the time.
BOB	*A. No* change. 	60 to 50	----------	No changes assumed to present layout. Noise restricts use of takeoffs from 4L and landings on 22R to some extent. Arrival/departure ratio during peak periods is over 2:1. No simultaneous IFR capability now exists at Boston.
	B. Add new runway 15L/33R and make it, plus all other runways, "dual lane." Assume $\sigma = 5$ sec. for CCS; 2-mile spacing and speed class sequencing. Also assume noise restrictions lifted, and runways extended to lengths shown on current ALP. 	210 to 84	56	Since terminal b located to one side, speed segregation does little good. Cost shown includes very rough estimate for reducing noise problem. The 210 capacity is related to favorable intersection use such as 4L, 9, 4R. The 84 capacity relates to use of 9/27 only, which will occur less than 1% of the IFR time because of strong winds. The average hourly IFR will thus be close to the set of parallel dual-lane runway capacities or 190 (this assumes simultaneous IFR arrival capability at spacing of about 2000 to 2500 feet).

TABLE 16.—*Capacity increase examples*—Continued.

Location	Description of capacity improvement	Approximat IFR hourly capacity	Cost ($ million)	Remarks
CLE	A. No change. 	60 to 50	....	No changes assumed to present layout. Simultaneous VFR not now possible on the two 5/23 runways when large aircraft are operating.
	B. Add new "dual-lane" runway 9R/27L and convert existing runways to "dual lane." Extend runways to sufficient length for airlines. Assume CCS, σ=5 sec.; 2-mile spacing; and speed class sequencing. 	190 to 84	41	Majority of costs obtained from recent city estimate and include extension of 18R&L (shown as one dual-lane runway in this exercise) and construction of new 9R/27L. Simultaneous IFR arrival capability in 9/27 direction (190 figure) would be possible over 80% of actual IFR weather, and over 85% of all weather conditions.

3.2.4 Related Major System Considerations

In addition to the airport capacity and control problems, there are other factors that require careful considerations during the airport concept and design activity. Some of these factors are briefly discussed below.

Airport Surface Capacity, Control, and Guidance

As the runway capacity for acceptance of aircraft is improved, the capacity of the ground system becomes a limiting factor. In general, a taxiway system must be carefully planned to minimize the number of intersections, provide a minimum of restrictions to and from the runways, and maintain a smooth flow of aircraft and ground vehicles with a minimum of deceleration and acceleration. In the case of existing and modified airports, a careful analysis must be conducted to determine the optimum flow patterns and control system to be used. The taxiway flow pattern places a major requirement on any new airport design.

Solutions that involve vectoring of aircraft and/or vehicles on the ground by ATC personnel should be avoided if possible since they add complexity in equipment, communications, procedures, and additional workload to the controller. Ground navigation responsibilities should remain in the aircraft or vehicle, but subject to a ground traffic system.

The ground control and guidance system must provide the following:

1. Steering and positional information that will enable the pilot to track along the runway and taxiway at appropriate speeds

2. Detection of the location of all aircraft and vehicles on the runways and taxiways for display to the ground controller

3. Selection of the optimum routing for each aircraft from its starting point to its destination on the airport surface

4. Guidance and control information along the taxiways on the routing selected on the airport surface, including desired speed and changes in taxiways

As in the present system, the basic system is operated by visual observations made by the controller and control instructions issued through voice radio channels. Light signals from the tower are also available for emergency conditions and radio backup. When electronic detection systems are added to the runway and taxiways, a display can be provided in the tower cab for use by the controller. There are a number of detection means available including radar, Doppler, magnetic and rf loops, etc., which have been investigated for this application. As a next step, a light signaling or other guidance system can be added to the runways and taxiways and operated by the controller for control and guidance of the aircraft and ground vehicles A major step can be taken with the addition of a digital processor in the tower to perform the functions of display generation, identification, tracking, routing, sequencing, conflict detection, and conflict resolution. When a data link is available between the aircraft and ground facility, a more complete automatic system appears feasible.

Passenger Capacity

The expected gains in the capacity of the air traffic control system and the airport runway-taxiway complex discussed earlier will impose a tremendous strain on the airport terminal facilities and access routes to handle the expected volume of passengers and goods. Using an average aircraft payload of 115 passengers per airplane and a l&hour day, at an aircraft rate of 244 operations per hour, approximately 441,000 passengers per day must be handled. The busy-hour traffic at a parallel runway airport of the future could be as much as the average daily traffic was in New York (Kennedy) or Los Angeles (International) in 1964.

The present access roads and automobile parking facilities at many of today's major airports are either inadequate or taxed very close to their capacities. The addition of traffic commensurate with the increase in capacity of the airway and runway system will place an increasing burden on the terminal processing functions, parking facilities, and airport access in the future.

Recent surveys at several hub airports showed that approximately 70 percent of the passengers and 90 percent of the airport employees gained access to the airport via private automobile. In addition, the surface vehicles needed to supply the business and support functions of the airport added considerably to the daily traffic count. Samples at two airports show that surface traffic movements are approximately double the number of passengers (26,000 and 32,000 passengers per day versus 50,000 and 80,060 vehicle trips on and off the airport).

Some of the solutions that have been suggested to alleviate the terminal building congestion problem include the following :

1. Consider establishing satellite or downtown (or remote) terminal areas for the ticketing, parking, and baggage-handling functions of originating and terminating passengers. These terminals can be served by V/STOL and rapid-transit systems. For example, a 10-car train operating with a B-minute headway can move 30,000 people per hour in one direction.

2. To save on terminal building land requirements, consider double-decking aircraft ramp areas wherever possible (such as for V/STOL operations) and the multiple-decking of car parking areas to allow for greater parking capacity and to provide additional airport land for aircraft requirements.

Airport Ground Facilities

The Committee is also aware that aircraft movement increases of the volumes foreseen herein would make prodigious demands upon airport service functions beyond passenger access and accommodation, The provision of adequate cargo processing and distribution systems, the provision of services and amenities for airport employees and the provision of adequate internal passenger distribution systems are several examples of the types of problems that would have to be met.

Wake Turbulence

Operations at closely-spaced parallel runways during VFR conditions have a good safety record with respect to wake turbulence. This record has been achieved by procedural techniques such as using caution when a light aircraft follows in the wake of a heavy or V/STOL aircraft.. It should be possible to develop procedures even with close runway separations under IFR conditions to keep light aircraft out of the turbulent wakes of heavy aircraft.

However, today's procedural cautions nnd pilot education devices are at best general guidelines which may become obsolete, especially in view of the larger types of aircraft which are now in production (i.e., 747, C-5A, SST). If it is found that, procedurally, wake turbulence imposes intolerable constraints on capacity, the alternatives are few. Either the vortex generator must be aerodynamically redesigned to reduce the effect, or dissipntion devices may he employed between aircraft. The latter course, is obviously, limited to the near-surfnce problem.

A study was conducted of one type of dissipation scheme involving suction trenches on either side of the runwny threshold to remove the vortices (Reference 15). This configuration was examined only from the standpoint of theoretical feasibility and not fully explored for operational practicality. However, the study was undertaken for four aircraft types, the 737, the 727, the 707, and the 747. The investigation explored the feasibility of aerodynamically isolating one runway from another, as well as clearing a given runway of the trailing vortex. Bnsed on the limited computations conducted, it appears feasible to dissipate severe vortices within reasonable bounds of suction power. For example, the vortex generated by a 747 at a 50-foot altitude can be sucked into a 1000-foot long 200 foot wide ditch on either side of the runway by fans using approximately 2000 horsepower.

The state of knowledge in this aren is incomplete. Very little testing or analysis directly relating to the terminal situation has been accomplished. The physics of vortex generation is fnirly well understood. Its general behavior is know; for example, it disperses more quickly in turbulent air; it sinks below the flight level as it trails; it moves with crosswinds; and it behaves differently near the surface than at altitude.

However, more in-depth attention must be devoted to this overall question to fully assessthe impact and to establish the corrective courses of action needed.

3.3 THE AIRSPACE SYSTEM

The airspace is categorized to define the services provided by the air traffic control system in various geographical regions, altitudes, and stages of flight. The present system provides three mnjor categories of airspace, each with its associated separntion service nnd concomitant requirements on the pilot and aircraft. These nre Positive Controlled Airspace in which IFR procedures are in force at all times for all occupants; Controlled or Mixed Airspace shared by participants following IFR procedures who are guaranteed separation from each other by the control process, and other participants following visual flight rules (VFR) depending for separation on procedures and "see-and-avoid" capability; and Uncontrolled Airspace where sepamtion is provided by procedures and "see-and-avoid" capability for all participants.

The Committee finds that these present broad definitions of airspace should be retained. Hoe-ever, there are important implications of increased traffic that require increased levels of service in portions of the airspace as well as increased equipment requirements on the part of the user.

One implication of increased tmffic is the requirement for a higher-quality service in high-density terminal airspace than now provided. An increase in the precision of aircmft control is necessary to obtain single-runway acceptance rates consistent with demand. It was shown earlier that lateral and longitudinal separations can be reduced safely and provide increased airport operating rates, assuming that the aircraft and the airspace have the updated ATCRBS and the microwave ILS.

The Committee sponsored an investigation into the capacity of a manual and semi-automatic control system to handle dense traffic in terminal and transition airspace. The conclusion is that, with area navigation routes (based on improved VOR at certain sites), with increased automation for the controllers, and with additional sectors and rerouting as required, controllers can handle forecast traffic into the 1900's. However, the number of controllers required to serve airspace modified to this extent will be substantial.

Mixed Airspace presently provides considerable freedom for uncontrolled traffic. A threat to the freedom of mixed airspace arises from safety considerations associated with a projected increase in midair collisions because of the projected increase in traffic density. This is discussed in Section 3.3.2.

There are many techniques for maintaining this freedom with safety as trafllc increases. All of the techniques require that all aircraft in the airspace be located and that most can be identified and addressed by data link. The functions of location, identification, and addressing can be accomplished by the upgraded ATCRBS. This capability can be used in many ways.

A ground computer complex, utilizing aircraft position supplied by ATCRBS, can determine any impending collision with another controlled or uncontrolled aircraft. Commands can be sent to the aircraft involved to prevent the collision. Such commands should be provided automatically via the data link of the upgraded ATCRBS. We call the provision of collision avoidance maneuvers in Mixed Airspace Intermittent Positive Control since an aircraft is controlled actively only when threatned.

The same data link and cockpit display required in IPC can be used to aid uncontrolled aircraft to ,detour regions of airspace which they are to avoid. In certain cases, it could be both safe and expeditious to segregate the airspace into controlled and uncontrolled corridors or regions. The location, identification, and data-link capabilities of the upgraded ATCRBS allow this to be accomplished since such corridors or regions can then be navigated, monitored, and policed. For example, one 'might be able then to implement "VFR" highways" in dense hub areas using the data link and ground computer to mark the "curbstones."

3.3.1 Positive Control

Positive Control Air-space now exists above **18,000** feat in the Northeast and 24,000 feet in the remainder of the country. Only controlled aircraft are permitted in this airspace, and separation service is provided by the ATC system. As developed in the analysis of Near-Midair Collision (NMAC) statistics which follows, positive control provides **the least** collision risk.

Effect *of ATC Separation Service*

It is shown in this section that positive control **of** air traffic from the ground increases the safety **with** which that traffic moves. That is, for a given **number** Of operations, it is found that there are **fewer** IFR/IFR conflicts than VFR/VFR conflicts **or** IFR/VFR conflicts. This is determined **by comparing** the relative incidence of AC/AC [8] **near-misses** and those of other user combinations **with** the expected incidence based on the hours **flown by th**e various users.

[8] AC/AC=an air carrier in a near miss with another air carrier.

TABLE 17.-Comparison oj near-midair collisionion data.

Type incident	Traffic factor, F	Percentage of total traffic factor (%)	Percentage of total NMAC's within 250 feet
AC/AC	3.6	3.4	1.1
ACIGA		23.3	22.0
AC/ML	12.2	11.5	6.2
GA/GA		19.2	34.6
GA/ML	35.4	33.4	26.4
ML/ML	9.7	9.2	9.9

The results of such a comparison are given in Table 17. In making this computation, the actual number of NMAC's within 250 feet have been estimated from the number of reported incidentss The traffic factor, F is proportional to the product of the number of hours flown annually by the two classes of users (or one-half the square when only one class of user is involved) times the average relative velocity. This traffic factor has been expressed as a percentage of the total tmffic factor, and the near-misses have been expressed as a percentage of the total near misses.

The limitations to this gross analysis are (1) the different users typically fly different types of aircraft at different distances and altitudes, thus spending different fractions of total flight hours in high density areas; and (2) the various users share airports to different extents with themselves and other users, and this affects the relative exposure to collision.

On the other hand, the comparison of ML/ML [10] incidents with AC/AC incidents overcomes many of these objections since length of flight, the use of relatively few airports, and altitude distributions are similar. However, the ML flight is predominantly VFR, and the AC flights are predominantly IFR. Table 17 indicates that the ML/ML interaction is approximately the expected share, but the AC/AC interaction is only one-third of that expected. The implication is that the scheduling and monitoring of flights from the ground are a relatively effective means of achieving separation as compared with a reliance on the see and avoid" doctrine.

One can interpret the disproportionately high GA/GA NMAC and the disproportionately low GA/ML and AC/ML to reflect the utilization of the same airports by the GA users as contrasted with the use of different airports by other pairs.

• Near Midair Collision Report of 1968. DOT, FAA, 1969.
10 ML=milhry.

Terminal/Transition Airspace Capacity

The Committee concluded that some form of positive control should be extended to high-density transition and terminal airspace to maximize the utilization of the major hub airports. Delays discussed in section 3.1.3 often run 30 to 60 minutes or more per aircraft during the peak hours. Inadequate airport capacity is the principal cause of the delay. However, it is estimated that approximately one-third to one-half of tha total delay at the five major terminals is attributable to controller overloads, equipment outages, and the inability of the system to predict and react promptly to transient, adverse conditions suc.h as severe weather and runway blockages.

To obtain additional airport and transition/terminal airspace capacity, the following are needed :

1. Higher operating rate per runway. This indicates greater precision in delivery time to the runway threshold-5 seconds as compared to the estimated current manual accuracy of 30 seconds. It also requires a decrease of longitudinal separation to the recommended 2 miles. Terminal automation of the sequencing and spacing function and the microwave ILS are needed to meet these objectives. The terminal control system supplies, throughout transition airspace, vectors and speed control consistent with the desired accuracy of delivery to an approach fix. Preferably, these commands should be supplied via data link. The time of delivery to the approach fix takes into account the announced final aircraft approach speed as well as updated information on winds aloft that become parameters in the computer-derived control function.

2. Closer-spaced independent parallel runways. This implies closer spaced terminal and transitional routes, requiring greater accuracy and reliability in the surveillance function that can be provided by the upgraded ATCRBS. It also requires increased use of three-dimensional area navigation routes.

3. Additional control function capacity, which is achieveable by additional sectors, rerouting, and automation.

4. Curved approaches to the inner marker, and variable glide-slope when appropriate for noise abatement or V/STOLs. The scanning-beam microwave ILS provides this.

The Capacity of th Control Function Under Manual Operation

The Committee attempted to determine the ability of the control system and controller to handle the increased demand as improvements to the system are implemented. These studies examined the New York transition and terminal area on the basis of controller workload." The New York area was selected since most problems characterizing high-activity terminal areas exist in this complex. The results are believed to be applicable to other terminal/transition areas.

A system model considering traffic density, route configuration, distribution of traffic in altitude, and aircraft mix was developed. Different combinations of these factors represent the loads on the controller. To measure the load or "complexity," difficulty weightings associated with each type of interaction between two aircraft, such as "same path" and "different path," "level-level," "level-climb," "level-descent," "descent-descent," were assigned as shown in Table 18. Based on actual or projected traffic and routing, the "complexity" of the various critical points (airways, important navigation aids, or intersections) in each control sector was calculated. The results of the study are discussed below.

TABLE 18.-"Transair" *complexity weighting factors.*

Mode	Same path	Different Path
Level/level	1.0	3.0
Level/climb	2.5	3.5
Level/descent	2.5	3.3
Climb/climb	1.1	3.3
Climb/descent	4.0	5.0
Descent/descent	1.1	3.3

At airspace demands equal to the present capacity of the three major airports (plus over-traffic) , only one control sector out of 23 had a complexity rating over 1000 that was judged to be its limiting capacity (see Figure 9). When a three-fold increase in traffic was applied, 10 sectors exceeded the complexity rating of 1000 and were considered to be overloaded (see Figure 10).

The tripling of the complexity per sector in Figure 10 as compared to Figure 9 is directly a result of the model assumptions. However, the model does show how many sectors approach saturation at the assumed complexity limit. It indicates that many additional sectors would have to be added and manned to cope with the traffic It also indi-

11 See Appendix C.

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path	Different path
1.0	3.0
2.5	3.5
2.5	3.3
1.1	3.3
4.0	5.0
1.1	3.3

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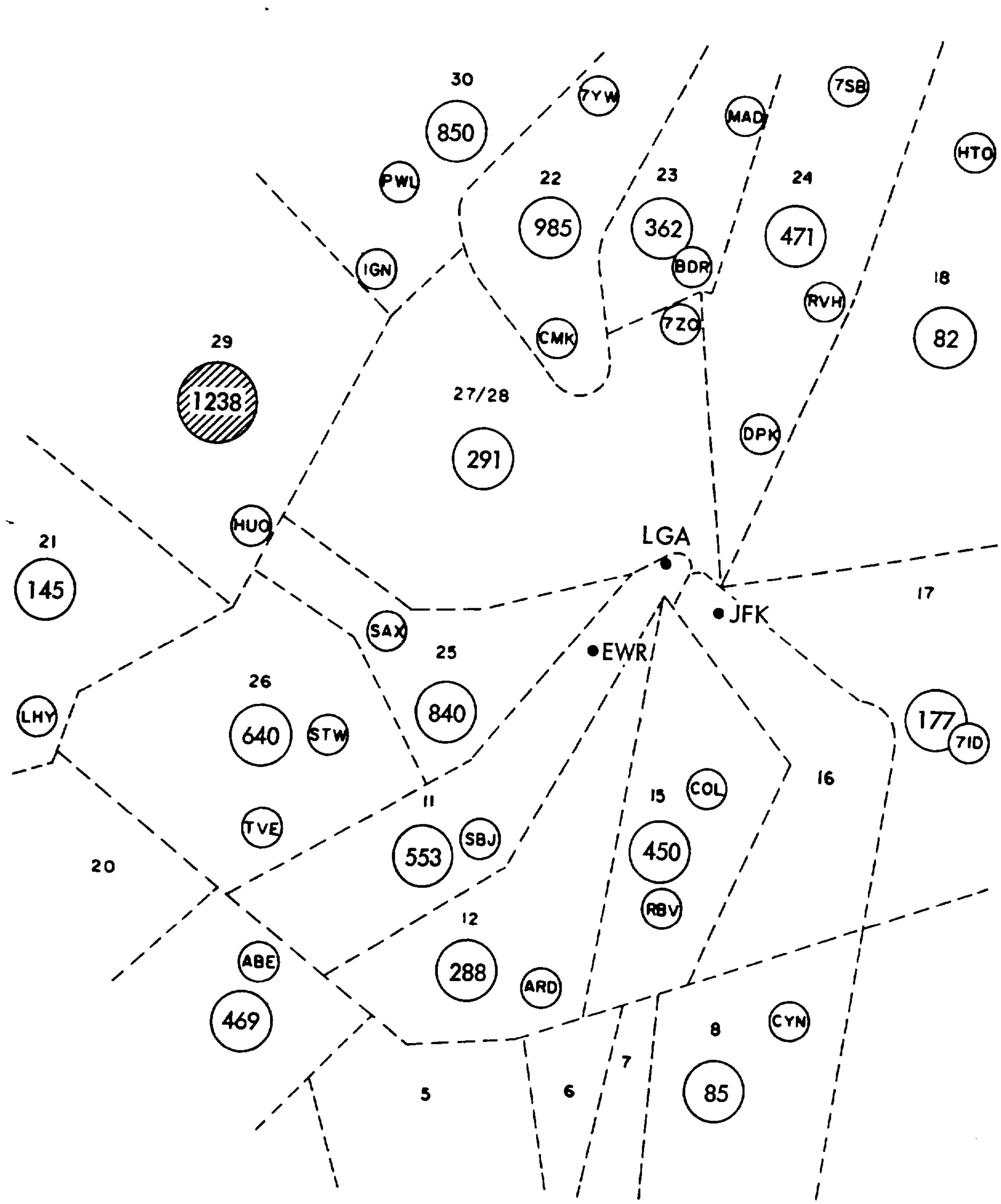

FIGURE 9.—Transition sector loading—present traffic density.

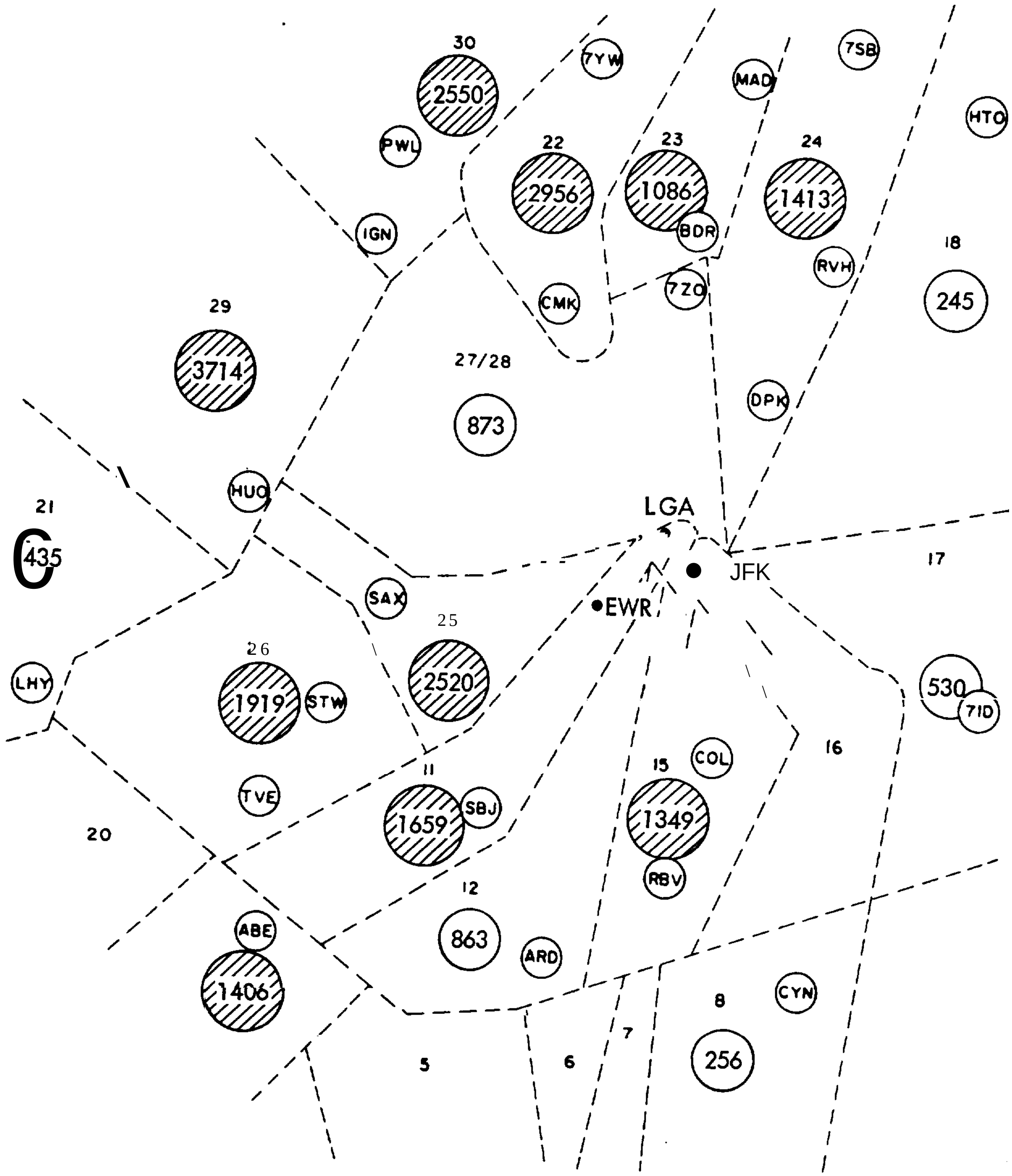

Figure 10 -Transition sector loading-three times present density.

cates that rerouting would be necessary to equalize sector loads.

Two additional airports, each generating traffic equivalent to the present JFK, were added at Calverton, L.I., and Solberg, N.,J. This traffic was in addition to the present load. Route structures feeding these airports were designed to avoid, insofar as possible, the critical points that are already heavily loaded in the current. system. Although the capacity of the area was increased by the equivalent of two JFKs, the results showed that only three sectors had complexity ratings in excess of 1000 (see Figure 11).

Increasing the traffic capacity of the New York area by adding two jetports (each with capacity equivalent to JFK) at Solberg and Calverton did not pose as serious a sector capacity problem as tripling the capacity at the present airports.

The complexity of present sectors seems to increase with the number of aircraft handled per hour in a manner that approaches a square law, as shown in Figure 12. The conclusions regarding the increase in sectors with traffic in Figures 10 and 11 are based on a complexity that varies linearly with traffic and, in that sense, may be optimistic.

FAA studies show that with the use of area navigation, routes can be designed which reduce the IFR conflict potential (necessary controller interventions) in the transition area by 28 to 60 percent depending on the type of sector. This, in turn, reduces the controller workload. The decrease in workload depended on having a major portion of the fleet use area navigation. Such a design is shown in Figure 13 and can be compared to current routes shown in Figure 14. The route widths used in the structure of Figure 13 are 8 miles. In the vicinity of the current en-route and terminal surveillance radars a separation of 3 miles may be utilized. Route separations of 2 nautical miles are feasible using the upgraded ATCRBS for surveillance and within 25 miles of a good VOR-DME installation (at same sites this might require doppler or precision VCR). It has been shown that such route widths are sufficient to handle at least a five-fold increase in New York area traffic which is the 1995 projection.

To summarize, it does appear possible to increase terminal airspace capacity by possibly a factor of three by rerouting, additional sectors, and the use of area navigation. But this implies an increase in the number of controllers that seems to be at least linear with the increase in traffic. However, this is uncertain since there are inadequate data on the relationship between traffic levels, degree of sectorization, and the required number of controllers.

The Capacity of the Control Function with Automatic Aids

Communications is the most readily measured indicator of controller workload. Communication data from 24 of the New York area control positions were examined to assess the capacity increases expected from the implementation of the various levels of NAS and ARTS. Altitude information required approximately 17 percent of the total communication time. Messages concerning radar identification of an aircraft accounted for approximately 4 percent of the total communication time. Approximately 50 percent of the communication time is devoted to conflict resolution, spacing, and sequencing. Routine messages occupy approximately 20 percent of the total communication time.

This study indicated that controllers spend an average of approximately 46 percent of their time communicating. However, seven of the 24 controllers spent more than 60 percent of their time communicating, out of a feasible maximum of 80 percent. Thus, if automatic aids reduce the communication workload associated with (1) altitude and identity reporting, (2) conflict resolution, spacing, and sequencing, and (3) relaying of routine messages, the controller workload should be reduced and his capacity to handle traffic increased. This assumes that a data link can be used. In the ATCRBS, a data link is used air-to-ground for just this purpose. For ground-to-air communications, data link can be used most effectively to relay computer-derived instructions. Thus, if a ground-to-air data link is to be used to lighten the controller load beyond that provided by ATCRBS, a computer must be used to perform the functions of conflict detection and resolution as well as spacing and sequencing.[12] The use of computer-derived control functions along with ground-to-air communications would substantially decrease controller workload.

The Committee's study attempted to assess the magnitude of these controller workload reductions. Based on observation of the amount of time controllers in the New York ARTCC consumed in the various control functions (as described earlier)

12 In this mode of operation, it would still be possible to have the controller approve any computer-derived data link message before transmittal.

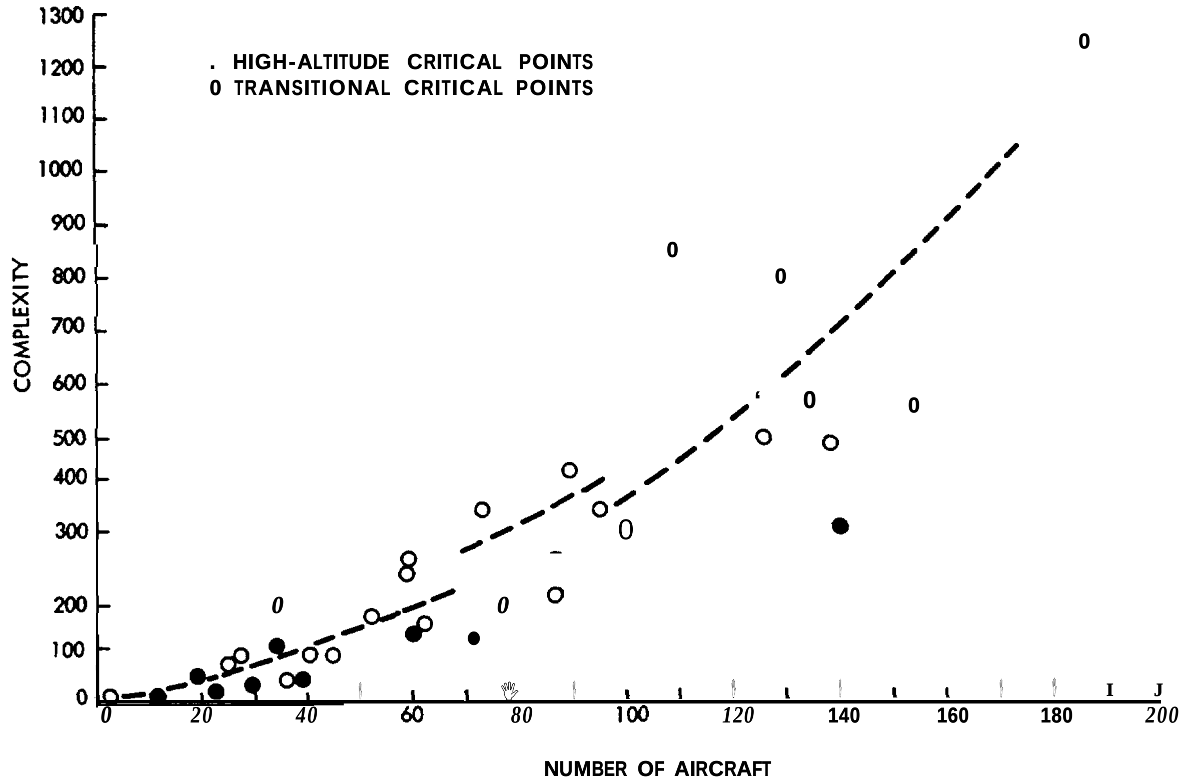

Figure 12-Complexity rating vs number of aircraft

the complexity workload factors **in Table** 18 were reduced by the factors in Table 19. The reduced complexity workload factors were then applied to the critical points of the transitional airspace of the New York area with the results shown in Figure 15. The increase in traffic level or decrease in controller workload is indicated for various jurisdictions and for various levels of automation. It is assumed implicitly that data link is used to transmit computer-derived functions and that the process is monitored by the controller. The results are that the increasing levels of automation should provide a factor of two or three increase in the amount of traffic that a single controller can handle.

TABLE 19.-Complexity weighting factor *reduction* **(in percent).**

Jurisdiction	Reductions			
	1st: Altitude (percent)	2nd: Altitude identification (percent)	3rd: Altitude identification conflict detection and resolution (percent)	4th: Altitude identification conflict detect and resolution spacing and sequencing (percent)
Transitional (Examples: SBJ, PWL, HUO, etc.)	L 10 C 15 D 15	L 10 C 20 D 20	L 50 C 50 D 50	L 65 C 70 D 70
Low level (Common IFR room—Area: arrivals to and departures from JFK, LGA, EWR)	D 0 C 5 D 5	L 5 C 5 D 10	L 40 C 40 D 45	L 60 C 60 D 60
High level (High-altitude sectors)	L 10 C 15 D 30	L 10 C 20 D 30	L 50 C 50 D 70	L 61 C 70 D 80

NOTE.—L/L Complexity Weighting shall form the "Floor"—i.e., no complexity weighting as a result of a reduction will be allowed to become less than that of the L/L *interaction*.
Key: L=Level—D=Descend—C=Climb.

Thus, a factor of up to three in terminal/transitional airspace capacity can be obtained by adding sectors, controllers, and rerouting, and another factor of up to three in airspace capacity can probably be obtained by decreasing the controller workload by automation aids. In this way, it seems possible to increase the capacity of the control function to handle traffic into the 1990's, but at the expense of a large controller work force.

3.3.2 Mixed or Controlled Airspace

This is an airspace shared by both controlled and uncontrolled aircraft.[13] The controlled air-

[13] It is not always true that controlled aircraft are IFR. It is possible to have VFR aircraft under control. This assumes that the control system has sufficient knowledge of the weather so that it does not direct a CVFR (Controlled Visual Flight Rules) aircraft into weather beyond its capability.

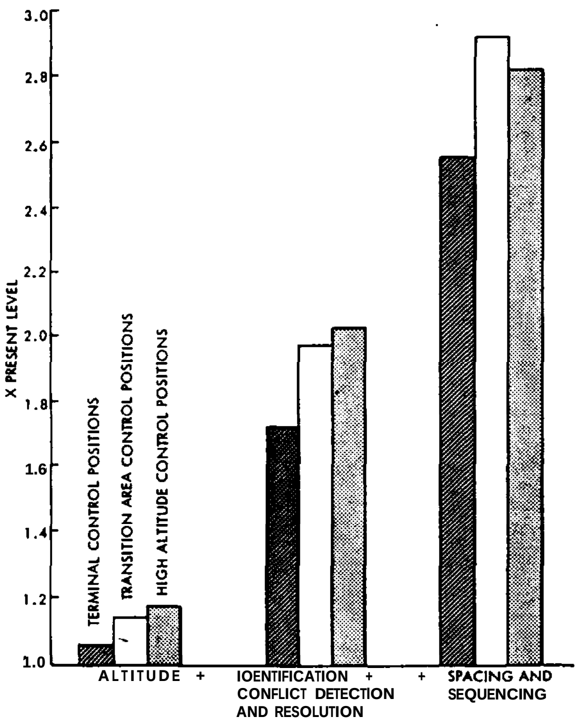

FIGURE 15.-Increase in traffic level by jurisdiction and staged improvement.

craft are flying cardinal altitudes in accordance with a flight plan known to the air traffic control system or in accordance with directives (clearan~) obtained by communication with the ground. Uncontrolled aircraft are flying at the cardinal altitudes plus 500 feet, abiding by the hemisphere rule, which requires them to be at the odd cardinals plus 500 feet when flying a heading of 0 to 179 degrees and at the even cardinals plus 500 feet when flying from 180 to 359 degrees. Separation in level flight between controlled and uncontrolled traffic is provided by the see-and-be-seen concept and by the altitude segregation just described. Separation between controlled and uncontrolled traffic during climb and descent is provided only by "see-and-avoid!' capability.

Thus controlled aircraft in line flight are vertically separated by 1000 feet, and from uncontrolled aircraft by 500 feet altitude and "see-and-avoid'? regulations.

Altitude errors (Reference 16) seem to indicate that the effectiveness of 500-foot separation between controlled and uncontrolled aircraft is questionable when compared with the 1000 feet provided between controlled aircraft. The increasing use of ATCRBS transponder altitude (Mode C) will permit detection of blunders and intervention through ground monitoring, particularly as the level of ATC automation increases. The use of calibrated static **systems for** general **aviation or,** perhaps more imporbntly, autopilots that have an altitude-hold capability, would tend to make the 500-ft separation between controlled and uncontrolled aircraft more effective. However, there is still a difficulty in calibrating altimeters dynamically on a regular basis.

Mixed Airspace provides freedom in a major portion of the airspace for uncontrolled aircraft. However, the collision rate 'between **air carriers** (AC) and general aviation (GA) in this airspace in the last few years is of concern (see Table 20). Furthermore, an analysis of the Near MidAir Collision (NMAC) statistics, which follow, shows that NMACs and, presumably, Midair Collisions (MAC), increase as the square of traffic.

Since the midair collision risk grows as the square of traffic and other accidents grow directly with the traffic,it is apparent that, as traffic increases, the fatalities **caused by collisions would** increase faster than those caused by other causes.

The fatalities caused by collisions will probably reach an unacceptable level with projected increases in traffic if **present** means of providing separation betaeen GA and AC traffic are not improved. This conclusion is now developed.

Since there is a far greater number of NMAC's than MAC's, it is preferable to use the larger data base to infer the actual collision hazard. However, it must be shown that the NMAC's **and MAC's are** really two aspects of the same phenomena. One indication of this is the great similarity in the circumstances surrounding actual MAC's and certain critical NMhC's as summarized in **Table 21. An**other indication is the agreement between the expectation of collisions between AC and GA and the actual number of midair collisions.

The expected number of collisions between AC and GA can be derived from the NMAC statistics for 1968 as follows. In 1968, there mere 103

TABLE *20.-Collisiona* ***and "hazardous near misses"*** ***between*** air ***carriers*** and general aviation.

Year	Traffic factor AG×GA× 10^{-12}	AC/GA inferred near misses <250 ft.	Collisions
1968	392	485	3
1967	307		2
1966	244		1
1965	190		1
Total	1,133		7

TABLE *21.-Critical NMAC's* **incidents** *vs.* midair ***collisions (terminal airspace).***

	Number	In traffic pattern	Below 2000 ft. within 5 miles of airport	Arrival or landing		Phase of flight			Relative position			Communications contact	
				Both	One	Descend Both	Descend One	Level Both	Head-on	Crossing	Overtaking	Tower	None
Critical NMAC's	108	70%	75%	50%	29%	39%	28%	13%	2%	43%	55%	22%	53%
Midair collisions	78	85%	90%	60%	25%	41%	23%	14%	2%	37%	61%	23%	73%

NOTE.-Data based on-
1. 1968 critical NMAC terminal incidents with closest proximity of 150 feet or less.
2. Terminal midair collisions recorded for 1965, 1966, 1967, and 1968.

NMAC's between AC and 6-4 reported by the AC, 44 reported by GA, and 14 reported by both. These NMACs occurred with a miss-distance of less than 250 feet and with less than 5 seconds from the time of first sighting. At these small miss distances, the probability of a maneuver influencing the occurrence of collision is considered small. From the reports of these NMACs (within 250 feet) by either the AC and the GA, or by both the AC and GA, it can be inferred that approximately 485 such incidents actually occurred." The collision cross-section in an AC/GA encounter is approximately 2000 square feet. If it is assumed that a miss between aircraft is caused merely by chance when it is less than 250 feet, then the factor

$$\frac{2000\ \text{ft}^2}{\pi \times 250^2} = 0.01,$$

determines the number of collisions that result from the inferred number of NMAC's within 250 feet. This would predict 4.9 such collisions in 1968, whereas actually three occurred.

Furthermore, there is a high correlation, 0.897, between AC and GA NMAC's and the traffic factor in the 21 major terminals. This permits us to add the traffic factors in Table 20 for the 4-year period of 1965-1968, infer the number of 250-foot NMAC for the 4-year period from the traffic factors, and compute from the actual number of collisions the factor relating collisions to 250-foot NMAC's. This factor for the 4-year sample turns out to be 0.5 percent,[15] whereas the 1968 statistics gave approximately 0.6 percent." The geometric factor gave 1 percent. Thus there seems to be remarkable agreement between the various methods of computing the expected number of collisions.

There is, in summary, much evidence that the collision hazard between controlled and uncontrolled traffic is proportional to the product of the number of operations of the two classes of traffic. In the case of AC/GA interaction, insofar as this consists of IFR and VFR flight respectively, we are led to expect approximately 2.5 collisions per year at the current traffic load. If both AC and GA traffic grow by a factor of two, we would expect approximately 10 collisions per year by 1980 if there were no changes in Mixed Airspace procedures. The Committee considers this unacceptable. This led to the concept of Intermittent Positive Control (IPC), the object of which is to allow the freedom of flight now permitted without the collision risk implied by increased traffic. However, the equipment required for IPC could also be used to establish "VFR highways."

Derivaion of Traffic Model from Near Midair CoUision Study

One can consider that the interactions between controlled and uncontrolled aircraft in Mixed Airspace follow a random model as long as the uncontrolled aircraft have a uniformly distributed heading.

It can then be shown (Appendix Cl) that the expected number of conflicts between uncontrolled aircraft, N, and controlled aircraft, M, in a given region is expressed by

$$\text{expected conflicts} = N \times M \times X,$$

where I< is a constant of proportionality related to the speed, heading, altitude, distance from center of terminal, and traffic density of the groups of aircraft operating at each of the terminals. Most of these data are unavailable. In lieu of predicting Ii, we can choose it from the data to get a best-fit between the prediction of the number of operations by aircraft of each group to each terminal and the reported number of "near-misses" at each of these terminals. In essence, the objective becomes one of seeking a best linear fit between *a* factor proportional to the product of the number of operations of the two groups of aircraft and

"The standard deviation of thls Inference Is 27 percent.

[15] $0.005 = 7\left(\frac{485}{392} \times 1133\right)^{-1}$

[16] $3/485 = 0.006$

the reported NMAC hazardous incidents for the various terminals under consideration. When this has been determined, the correlation coefficient, the standard deviation, the uncertainty in the slope of the line, and other conventional statistical measures are available to test the validity of the model.

It is possible to see how well the model accords with the 1968 NMAC statistics. The 21 large air transportation hubs in the United States have been selected for calculation of a "measure of traffic" or "traffic factor." The traffic factor is equal to the product of AC and GA annual operations, treating GA local and GA itinerant traffic differently because of their different interaction. The traffic factor

$$F_1(30) = AC(30)\ [GA_L(O)\ + GA_1(3O)]$$

where AC (30) is the number of annual air carrier operations at a given air carrier airport within the hub with a radius of 30 miles; $GA_L(O)$ is the number of local GA operations at that air carrier airport, and $GA_I(30)$ is the sum of all GA itinerant operations within the 30-mile hub.

If there is more than one air carrier airport within the hub, the factors $F_1(30)$ for each air carrier airport are summed to obtain the factor for the hub as a whole. There is plotted, as a point (Figure 16), the number of reported NLX4C's during calendar year 1968 between AC and GA traffic within 30 miles of the center of each of 21 major hubs. The code for the hubs is given in Figure 17. A best linear fit to these points was determined, and the correlation coefficient was calculated to be 0.897. This is a high-correlation coefficient, and indicates the correctness of the model.

Extrapolation from the Random Model

If the number of operations increases by virtue of better utilization of existing airports or by building new airports in the same terminal area, it is possible to predict with some confidence the expected rate of reported near-misses by extrapolating the straight line in the graph in Figure 16 since the expected number of reported near-misses was directly proportional to the product of the number of AC and GA operations within the large air transportation hubs. For example, if these operations each increase by a like factor, then the expected number of reported NMAC's will increase as the square of that factor.

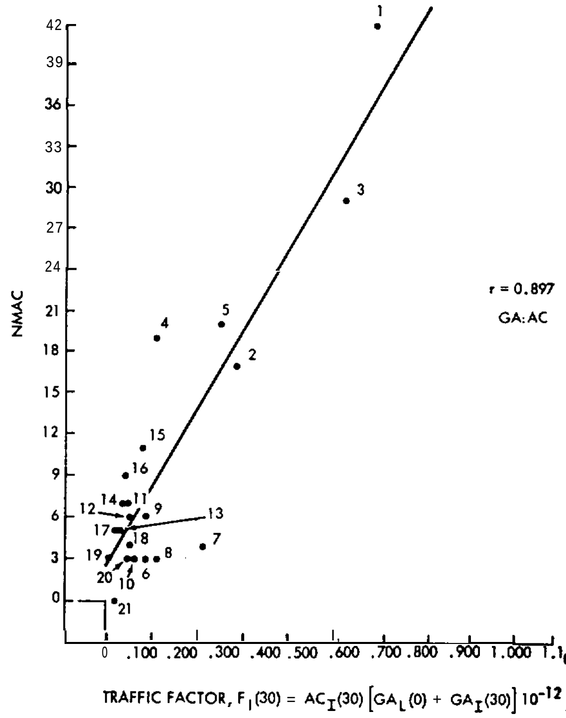

FIGURE 16. -Nearmidair collision incidents vs traffic factor for 21 large hubs, 1968

The prediction uncertainty can be estimated from the uncertainty in the slope of the line giving the best fit to the data. For example, for Figure 16, plotting the number of NMAC's versus the traffic factor F_1(30, the slope is 52.2 with 95-percent confidence that the true slope is less than 64.6 and more than 39.8. The uncertainty in prediction of the number of NMAC's for greater traffic factors is thus approximately 24 percent; i.e. (12.4/ ***52.2*** x 100).

ATL	6	MIA	
BOS	10	MKC	
CHI	2	MSP	
CLE	12	MSY	
CVG	21	NYC	
DAL	8	PHL	
DCA	4	PIT	
DEN	13	SEA	
DTW	9	SF0	
HOI'	17	STL	
LAX	3		

Note. The code corresponds to the hub rank in air carrier operations.

FIGURE 17.—Code for traffic factor/NMAC correlation graphs.

Alternative Methods for Providing Safety in Mixed Airrspace

There are many techniques that could decrease the predicted number of midair collisions in Mixed Airspace :

1. Place all aircraft under positive control.
2. Segregate airspace into controlled and uncontrolled regions.
3. Improve effectiveness of "see-and-avoid" by helping pilots to visually detect other aircraft.
4. Implement an air-derived Collision Avoidance System (CAS) .
5. Relay a ground-derived traffic situation display to all aircraft or an appropriately processed portion of it separately for each aircraft.
6. Maintain Mixed Airspace by ground-derived collision avoidance instructions data-linked from the ground surveillance equipment to aircraft; this is referred to as Intermittent Positive Control.

The difficulty with technique 1 is that it implies either banning the VFR pilot or providing an ATC system that has knowledge of the weather to an impractical level of detail. In order to provide reasonable levels of access to a great number of geographic centers separately for both controlled and uncontrolled aircraft, as implied by option 2, the airspace would be so complex that both controlled and uncontrolled aircraft might find it difficult to navigate. On the other hand, in certain locationsparticularly active terminal regions-it may be appropriate and possible to segregate airspace. One Committee-sponsored study attempted to develop a "VFR Highway" through the New York area from the south-west to the northeast. There was insufficient time to fully assess the feasibility of such a route structure? but it was clear that to safely monitor and police any such corridor in dense airspace it would be necessary for the ground to know the location of all aircraft and be able to provide rapid corrective maneuvers to any aircraft that may violate the corridor boundaries. This approach, therefore, implies an upgraded ATCRBS capability, including at least a modest data link for all aircraft navigating the airspace as well as a groundenvironment capable of devising, formatting, and transmitting the required messages.

Option 3 recognizes the possibility of reducing collision risk by improving the pilot's ability to detect other aircraft visually. This is the object of the current procedure of issuing traffic navisories and of development of pilot warning indicators (PWI) . Traffic advisories are now of limited usefulness because of a lack of altitude information. Also, controller workload is such that it is not always possible to provide advisories. An improvement in the effectiveness of advisories and PWI might provide an important benefit in safety at relatively low cost-and mill probably be an important factor in lower density terminals where other alternatives may be impractical.

Option 4 is discussed in Section 3.3.3. CAS offers the potential for backup of the ATC system for equipped aircraft except in the regions of densest traffic. Its cost will probably restrict its usefulness in separating VFR from VFR, and VFR from IFR traffic.

Option 5 concerns the relay of a ground-derived situation display to the aircraft. The use of such a display might be warranted as an aid to the pilot in visually acquiring other aircraft, or as a substitute for visual detection. That is, the pilot assesses the hazard or the situation display and maneuvers if necessary. Various questions arise :

1. If the situation display is used as an aid to visual detection, is it. as effective as verbal advisories?
2. Is the time spent looking at the display better spent in visual search?
3. If the pilot can visually acquire the target, can he better avoid it by looking directly at the target or by looking at the display of the target?
4. Is the net improvement in collision avoidance from a situation display, if any, worth the cost ?
5. Is the increment in ground equipment required to evaluate the collision hazard and select a maneuver significant compared to the cost of processing the appropriate data for transmission to each aircraft?
6. Is the communications burden of sending processed information to each aircraft tolerable?

The answers to these questions lead one to consider Option 6, Intermittent Positive Control (IPC) as preferable to Option 5.

Option 6, intermittent positive control, allows maximum freedom to VFR pilots at minimum cost to them in those parts of the airspace where collision risks would otherwise preclude VFR flight altogether. It remains to determine at what traffic densities the other options prove unacceptable.

Options 5 and 6 have similar intent-to aid the pilot in his separation function by relaying surveillance system data to the cockpit. The pilot should be distracted as little as possible from his piloting, navigation, and separation functions. He should be alerted only when necessary. Furthermore, there is a limit to the complexity of a situation display that can be readily interpreted. Unless the situation display is highly processed for each aircraft, showing intent and track of near-neighbors, it would be of little use. Even then, the pilot's derivation of an escape maneuver based on procedures and his individual interpretation of a processed situation display is not as certain as a consistent set of commands provided to both aircraft from the ground complex.

The feasibility of Option 6, IPC as a function of aircraft density, can be determined by resort to a gas model representative of aircraft in Mixed Airspace. In Appendices Cl and C2 there are derived the expected number of ground-derived collision avoidance commands to he relayed per hour to aircraft in Mixed Airspace at various traffic density levels. The minimum acceptable miss distance and the minimum acceptable warning time for providing commands to conflicting aircraft are two of the key parameters.

These two parameters can be interpreted as the volumes of space that surround each aircraft in the air (see Figure 18). The radius of the innermost circle is the minimum miss distance; the objective of the Ground Collision Avoidance System (GCAS) is never to allow any aircraft within this distance of any other aircraft, The outermost area, called the conflict space, contains all the points through which the aircraft could pass during the warning time. If the conflict spaces of two aircraft overlap, it may be necessary to give commands so that there will be no approach to within the miss distance.

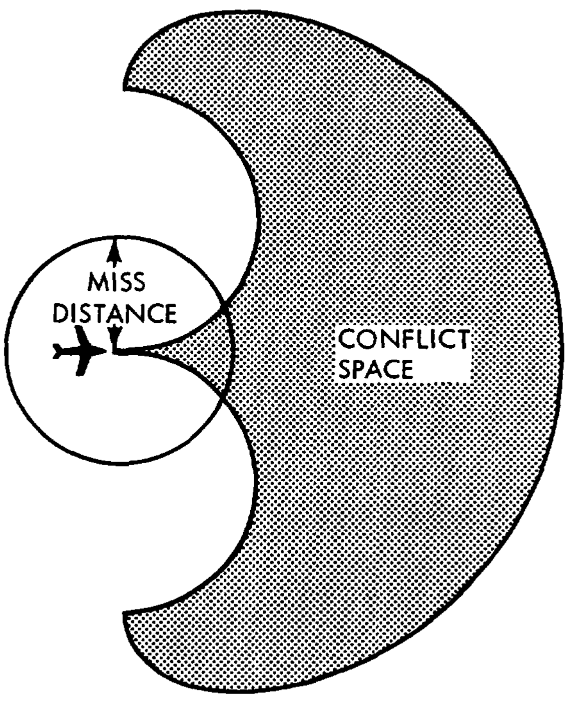

FIGURE 18.-Conflict space surrounding a single aircraft in a plane.

Two types of instructions are planned; one commands a maneuver to avoid approaching another aircraft within the miss distance, and the other prohibits course changes in certain directions. This second type of command prevents an aircraft from proceeding so far into a conflict space that it would be impossible to provide the first type of command within the minimum warning time.

If we calculate the number of times the inner areas come together, we have an estimate of the frequency of positive commands necessary to avoid minimum miss-distance approaches. Likewise, the frequency of contact of the larger areas gives an estimate of the frequency of "negative" commands required to limit the maneuvers available to the aircraft. The latter number includes commands of the first type.

These calculations are summarized in Appendices Cl and C2. Since the Los Angeles Basin (60 X 120 n.m.) surrounding the Los Angeles International Airport is representative of high-density, mixed-airspace regions, the estimated instantaneous peak airborne count for that region in 1995 has been used. These results are shown in Table 22 along with the assumed aircraft parameters.

The average hourly commands per VFR (uncontrolled) aircraft are given in Table 23 for a

TABLE *22.-Mixed airspace description, 1995, Los Angeles Basin*

Size=60n. miles×120 n. miles
Mixed airspace=altitudes 0 to 10,000 feet
Estimated peak instantaneous airborne count, Los Angeles Basin—60×120 n.m. (about 10 percent of center area)

User	VFR	IFR
AC	-------	40
GA	1,200	100
ML	20	5
Total	1.220	145

Aircraft parameters
Maximum speeds IFR = 500 ft/sec≃300 kt
VFR = 300 ft/sec≃200 kt
Maximum turn rate = 3 degrees/second (full rate)
1.5 degrees/second (half rate)
Maximum climb and descent rate = 1500 feet per minute
Minimumumiss distance = 2000 feet horizontal
500 feet vertical

TABLE *23.-Average hourly* commands *per VFR* aircraft, three dimensional model.

Airspace: 60 n.m. × 120 n.m. × 10000 ft.
Number IFR: 145
Speed IFR: 300 kt
Number VFR: 1220, 50 percent traveling at each speed
Speed VFR: 200 kt. and 100 kt.

Type	Warning times			Approach closer than 2000 feet
	20 sec.	30 sec.	40 sec.	
Turn rate: 1.5 deg./sec.:				
IFR-VFR	0.67	2.19	4.98	0.01
VFR-VFR	2.49	a 17	18.15	1.82
Total	3.16	10.36	23.13	1.83
Turn rate: 3 deg./sec.:				
IFR-VFR	1.41	3.73	7.59	.01
VFR-VFR	4.32	13.94	28.32	1.82
TOTAl	5.37	17.67	35.92	1.83

3 degree/second and 1 1/2 degree/second turn-rate maneuver freedom. The results in Table 23 do not seem to impose an unreasonable number of restraints or commands upon the VFR pilot. With a data acquisition system update rate of 1 to 3 Sec-- onds, a 20-second warning time would seem adequate. A slower data acquisition rate would require longer warning times and, therefore, a larger number of commands limiting maneuver. The results in Table 23 depend on obtaining aircraft velocity to an accuracy of approximately 50 knots, so VF'R aircraft can be classified in two speed classes, 100 or 200 knots. This can be accomplished by the data acquisition system. Should the density of aircraft in the Los Angeles Basin double with respect to the level indicated in the forecast, the number of restraining and collision avoidance commands per aircraft would increase proportionately.[17] At these density levels, the concept of intermittent positive control alone may not be a reasonable approach to preserving VFR freedom in Mixed Airspace. At these densities it is probably necessary to limit freedom of flight by more restrictive procedures.

The computer workload to accomplish IPC has also been estimated in Appendices Cl and C2 and integrated with the results of the overall automation studies reported in Appendix D. Approximately 10^6 computer operations per data acquisition cycle are required to provide IPC for twice the traffic density predicted in the Los Angeles Basin in 1995. This is well within the capability of the computer complex necessary for this period.

IPC, or its equivalent in certain regions, is required prior to 1980. It is recommended that the IPC function be incorporated in the upgraded Third Generation System. It should be determined in an early study whether the IPC function should be included in the NAS, ARTS, or near-data acquisition computer complexes.

3.3.3 Air Derived Collision Avoidance Systems

The Committee has heard presentations on (1) air-derived collision avoidance and proximity warning systems, (2) the FAA simulations with the "en route" logic of a collision avoidance system (CAS) operating in the Atlanta terminal environment, (3) the revised "terminal" logic of the CAS system operating in the Atlanta terminal environment, (4) the Pilot Warning Instrument (PWI) program of the FAA, (5) the Autonetics proposal to the FAA on an advanced National Airspace system using time and frequency techniques,[18] (6) a special time-frequency report [19] prepared by a task group for the Committee, and (7) a study entitled "Separation Hazard Criteria" [20] which compared air and ground-derived data requirements for collision avoidance systems.

The Committee has come to the following conclusions as a result of the review of this material :

1. The air-derived CAS currently under development requires cooperative equipment of considerable sophistication. However, the near-miss statistics indicate that the major collision threat occurs in Mixed Airspace as a result of the interaction of uncontrolled and controlled aircraft. It does not seem reasonable to ask participants in Mixed Airspace to carry the cooperative portion of the presently proposed air-derived CAS system in addition to the improved ATCRBS beacon with integral IPC data link.

2. An air-derived CAS that exchanges only range and range-rate has an alarm region that is greater under certain circumstances than current separations under VFR and even IFR condition (Reference 17). False alarms result whenever the CAS alarm region is greater than normal separation. Since separations are a function of the stage

[17] Appendixes C-1 & 2 were written for a much higher traffic estimate of 1990 traffic than our final forecasts could support. The computer sizing effort, which depends in part on the IPC estimates, was commenced before the forecasts were ready. The IPC estimates presented here are based on the traffic forecast in Section 3.1.

[18] "Advanced National Air Space System Using Time and Frequency Techniques"—VOL. 1—May 1969—FAA.

[19] "Time/Frequency Data Acquisition for Aeronautical System" DOT ATCAC Subgroup Report—F D Watson, McDonnell—Douglas, Subgroup Director, Appendix F-1.

[20] "Separation Hazard Criteria"—John M. Holt, Gene Marner, Collins Radio Company, Appendix C-4.

of flight-en route, transitional, or terminal-it would seem that the CAS alarm volume would have to accommodate to the stage of flight to provide safety with a low false alarm rate. As separations are reduced to increase capacity, the false alarm rate of the CAS will increase unless its alarm volume can be reduced equivalently. Additional information, beyond range, altitude, and range rate, could be derived or exchanged between aircraft. Exchange of aircraft heading and airspeed provides some cross-track, relative velocity information. This and an exchange of intent might reduce CAS alarm regions so that they would be smaller in all cases than present or projected separations. However, this would complicate CAS and make even the minimal cooperative equiipment more expensive. Widespread implementation of CAS would not then be readily achievable ; CAS effectiveness depends on widespread implementation.

3. Assuming a CAS system could be developed that could be compatible with separation standards, that could vary its alarm region with the stage of flight, that could be consistent with requirements of the data acquisition system, one would still have to compare the costs of wide implementation of airborne CAS with wide implementation of an IPC system or its equivalent. Since approximately 500,000 general aviation aircraft are expected in the fleet by 1995, there seems to be incentive to provide equivalent service from ground-based installations and minimize airborne costs.

3.4 THE AIR TRAFFIC CONTROL SYSTEM

The forecasted demand described in Section 3.1 set the requirements that the airport and airspace components of the air traffic system have to satisfy. Airport and airspace designs that satisfy requirements are described in Sections 3.2 and 3.3. These designs and the traffic demands set the requirements for the ATC system discussed in this section.

By 1995, approximately 10 to 15 times as many terminal aircraft will be receiving some kind of air traffic control service as in 1968: approximately fifteen times as many aircraft in the en route portion of the airspace will require ATC or IPC service as in 1968.

In order for high activity airports to handle the forecasted traffic, the Committee has recommended the use of close spaced parallels approximately 2500 feet apart, and smaller separation between aircraft on approach of the order of two miles. The accuracy and data rate of the terminal data acquisition system serving high density airports will havc to be improved to safely monitor this kind of operation. Furthermore, to obtain the single runway capacity required, it mill be necessary to sequence aircraft to approach fixes with much greater precision than has been accomplished heretofore. The ARTS terminal automation program will have to be expanded in order to accommodate these functions.

Ground-air-ground data links with data formatting done by the NAS, ARTS, and new computers associated with the updated ATCRBS system are an essential feature of the recommended ATC system. It is not as safe nor efficient to relay control messages by voice links at the high traffic levels that are foreseen in high density areas. It seems possible and desirable to have these data links share the same frequency assignments with the data acquisition system, and further it seems essential from a reliability point of view that data link messages flow over a single duplex channel nationwide.

The STC system required to meet the forecast demand efficiently and to provide safe separation between all users of controlled airspace must be highly automated. It was indicated in Section 3.3 that computer augmentation of a manual system, similar to that being implemented in the NAS program, can increase the traffic handling capacity of the ATC system by probably no more than a factor of three in high density areas such as New York. Capacity beyond this can be obtained by resectoring and rerouting. Perhaps even greater capacity can be achieved by higher levels of automation than contemplated in NAS Stage A and B, if this should prove feasible.

The navigation and landing aids should continue to be independent of the surveillance system to maintain reliability. The pilot is responsible for navigation in accordance with his ATC route clearance except when vectored by ATC for traffic avoidance and final approach spacing.

The navigation system for the upgraded Third Generation System should be based on the use of VOR-DME supplemented by airborne area navigation computers. Use of area navigation permits more direct routings and easier offset of routes for weather avoidance in the en route areas. In terminal areas, the route to be followed would be assigned by ATC prior to the flight's entry into the terminal area and the choice of the route assigned would be governed by the time adjustment that is required for each aircraft. In certain high density terminal areas, where approaches are being made to close spaced runways, terminal route widths of the order of 2 miles may be required. At these terminals, the required navigation accuracy can be provided by the VOR-DME system (certain sites may require improved VOR), although use of a flight director may be required to minimize flight technical error. The use of terminal tracks based on an area navigation capability also provides a means of direct transition from terminal track to final approach guidance in the event of ATC system failure.

The microwave landing system provides not only an all-weather landing capability but also guidance signal which permits curved approach and departure tracks to be flown accurately. Use of curved tracks permits approach and departure paths to be located for minimum noise exposure in urban areas. Although the over-all role of ground-air-ground communications is not recommended to change greatly, implementation of an automatic ground-air-ground data link removes much of the routine communications associated with the ATC control and radar advisory services from the voice channels, Implementation of the "VFR Highway:' and/or IPC functions relieves controller of the workload associated with the present radar advisory service while at the same time providing an improved service to the user.

Section 3.4.1 describes the Second and Third Generation ATC Systems. Cost of these systems are discussed in Section 3.4.2. The requirements of the upgraded Third Generation System are discussed in more detail in Section 3.4.3.

3.4.1 The Second and Third Generation System

The Second Generatim System

The present Second Generation ATC System, although it uses some computers for flight data processing, is primarily a manual system with regard to the control and separation of air traffic. The major elements of the system include : designated airspace volumes, rules and procedures, ATC facilities, airport and weather facilities, navigation and landing facilities, communication facilites, and the trained personnel who operate and maintain the system.

Airspace is divided into three major categories- Positive Control, Controlled or Mixed, and Uncontrolled. Positive Control Airspace currently exists above 18,000 feet in the northeastern portion of the United States and above 24,000 feet in the remainder of the country. Controlled or Mixed Airspace, in general, starts at some altitude above the ground and extends upward to Positive Control Airspace. In terminal area control zones, it extends to the ground. Uncontrolled Airspace underlies Mixed Airspace.

Air traffic control provides different services in each airspace. In Positive Control Airspace, all aircraft are under IFR control and the ATC system provides separation service between all aircraft. In en route Controlled or Mixed Airspace, aircraft operating on IFR flight plans are separated from other IFR aircraft and radar advisories are issued to these aircraft relative to the bearing, distance, heading, and speed class of uncontrolled aircraft detected by the ATC radars if the controller workload permits. Radar advisory service is also available on a time available basis to the pilots of uncontrolled aircraft on request again if the controller workload permits. In tower equipped terminal control zones, both VFR and IFR flights are controlled. In the high density terminal areas, sequencing and spacing service is given to both VFR and IFR aircraft through the use of radar control.

Airborne equipment requirements vary with the type of service desired. Aircraft operating solely in Uncontrolled Airspace or en route Controlled Airspace are not presently required to carry navigation, communications, or transponder equipment ; however, communications equipment meeting a limited channel capability requirement is needed for operations conducted at any tower equipped field. Pilots desiring weather information service while airborne will also need at least the limited channel communications equipment. Pilots desiring IFR service must have the necessary communications, navigation, and landing system equipment meeting certain specified accuracy requirements. In addition, aircraft operating in APC must be equipped with a transponder and distance measuring equipment.

Pilot briefing services are provided by flight service stations and airport reservation office (ARO), while control is offered from air route traffic control centers and terminal control facilities. Weather and NOTAM briefings, servicing of reservation requests for arrival and departure times at high density airports, and flight plan filing services are provided by the flight service stations. Flight plans may also be filed through military and airline operations offices and reservation requests may be made directly with the ARO. ATC is based on radar procedures in much of the airspace. This type of control separates aircraft on the basis of altitude or distance criteria. Where radar coverage is not available, non-radar procedures are based on providing route, time, or altitude separation between aircraft. At the present time, control of the en route airspace is provided from 21 radar equipped en route ARTCC's. Approximately 367 terminal facilities are equipped with a control tower and, of these, 117 are radar equipped.

The Third Generation System

The Third Generation System presently being implemented by the FAA is based on (1) limited automation to assist the human controller, (2) automated data acquisition, including identity, altitude, and position provided by the Air Traffic Control Radar Beacon System (ATCRBS) backed up by radar, and (3) voice communication. The automation consists of the NAS Stage A program for the ARTCC's, the ARTS III program for the top 64 terminal areas, and the Tower Bright Display program presently implemented in 88 tower cabs. The NAS 'En Route Stage A System was developed to increase traffic handling capability, improve the safety record, and provide better and faster service by providing :

1. Easy transfer and accurate processing and updating of flight information;
2. Bids for establishing and maintaining radar identification of aircraft in the system;
3. automatic display of altitude or flight level information with aircraft position ; and
4. A computer processing capability sufficient to permit automation of additional functions, such as conflict predictions and flow control.

The NAS En Route System for each center utilizes inputs from several long range radars and associated ATCRBS interrogators. Radar and beacon coverage is available throughout Positive Control Airspace. In the high density traffic areas, radar coverage is also available down to 3000 to 5000 feet above the surface, this providing nearly complete coverage of the air route structure in these areas. Although both radar and beacon coverage are available throughout Positive Control Airspace, control is based primarily on use of beacon replies as all aircraft flying in this airspace are transponder equipped. Primary radar data are available for display in the event of airborne transponder equipment failures and can also be caused by the controller to observe contours of storm areas existing in his sector. The NAS equipment system digitizes the radar video information at the radar site and transmits the data to the computer at the ARTCC where it is processed for display. Each radar site is capable of processing approximately 1000 target messages per radar scan. Since radar siting is such that redundant coverage is available for much of the airspace, the computer is programmed to use target reports from a preferred site for each area. If data from that site is not available on an aircraft, the program will accept data from a designated supplementary site to maintain that aircraft track. This approach allows the computer to always use the best data available for maintaining a track.

The ARTS III is a modularly expandable system that provides an operational capability that can be added to the existing terminal equipment. The number and type of functions implemented at a particular terminal will be dependent on the traffic demand and operational requirements at that facility, and the level of automation in the adjacent ARTCC. The initial capability that is being provided includes :

1. Automatic interchange of flight data, track positions, and transfer of control messages with the associated ,ARTCC;
2. Automation aids for establishing and maintaining identification of targets representing transponder equipped aircraft; and
3. Automatic display of altitude and ground speed information with aircraft position.

The initial operating capability to be provided by the ARTS III system is the digitizing, processing, and display of alphanumeric data associated with transponder equipped aircraft. This is presented using time-sharing techniques on the controller's radar indicator with the broad-band video information from both the airport surveillance radar (ASR) and the ATCRBS. Since the radar system is located on the airport, coverage of the approach and departure paths is generally good ; however, in some areas, high rise buildings close to the airport are creating coverage problems. Although the percentage of transponder equipped aircraft is increasing rapidly, data from both the ASR and ATCRBS is used for control. The terminal equipment system is designed to process up to 30 transponder equipped aircraft per sweep and up to 512 aircraft per scan. The capacity of the system can be increased further by modular addition to the computer.

3.4.2 ATC System Costa

The air traffic control system, as it exists in 1969, represents a large national investment. Since this investment has been made over a period of years, it is difficult to arrive at a figure showing the net worth of the existing system-i.e., the sunk costs diminished by the proper depreciation charges. However, the present unit, cost figures for many of these facilities are listed. These costs typically include site and/or building preparation, equipment procurement, installation, checkout, and final test, but exclude development cost.

The total cost (if bought today) for the facilities and equipments (F&E) now in place is approximately $1 billion. Table 24 deals with terminal air traffic control and navigation facilities. Table 25 presents costs for the en route area. Table 26 shows costs of the terminal and en route communication facilities. The additional planned investments for all the items through fiscal year 1979 total approximately $1.6 billion. These tables are taken from the FAA Planning Document, 1970-1979, and other sources. Table 27 shows a summary of FAA staffing plans for the coming decade. In the critical area of terminal and en route facilities, the controller population is expected to double. One can contrast the expected controller increase with the expected increase in operations they will be required to handle. Table 28 shows such a comparison for the en route case.

Assuming linear growth of operations and therefore people, the additional salary costs (above

TABLE 24.-FAA plans for terminal area F&E, FY 70 lo 79.

Terminal area ATC/NAV facilities	FY 69 unit costs (thousands of dollars)		Inventory (number)		Planned F&E investment, FY 70-FY 79 (millions of dollars)
	F&E	M	FY 69	FY 79	
Air traffic control:					
FAA towers and CS/T	254-791	16.7-111.8	370	530	38.3
ARTS I approach control			1		
ARTS II approach control	na	na	0	115	242.8
ARTS III approach control			0	113	
Surveillance:					
ASR [1] (FAA-operated)	1,019	46.9	120	242	192.2
Navigation:					
TVOR	60	7.9	48	126	
DME (added to ILS)	63.5	14.8	0	226	
DME (added to TVOR)	55.5	14.8	0	60	
ILS Cat. I			279	1,092	116.2
ILS Cat. II	na	na	1	75	
ILS Cat. III			0	24	
Visual landing aids	na	na	272	1,228	66.4
Visibility measuring instruments	na	na	154	(2)	22.1

[1] All but 6 are radar beacon equipped.
[2] All qualifying runways.

TABLE 25.-FAA plans for en route F & E, FY 70 lo 79.

En route ATC/NAV facilities	FY 69 unit costs (thousands of dollars)		Inventory (number)		Planned F&E investment, FY 70-FY 79 (millions of dollars)
	F&E	M	FY 69	FY 79	
Air traffic control: [1]					
ARTCCs (CONUS)	na	4,255	21	[2] 20	424.0
ARTCCs (outside CONUS)			6	6	.8
Total			27	26	
Surveillance:					
LRR [3] (FAA and joint-use)	1697-2326	103	84	112	196.7
Navigation:					
VOR or VOR/DME	na		240		
VORTAC	na	12.2-23.8	600	(4)	
PVOR or PVOR/DME	na		0		60.1M
Total [4]			840	840	
VOR test equipment	na	1.5	63	363	

Notes:
[1] All CONUS centers are to be NAS Stage A Model 3 (CDC)-equipped during the decade ending 1979. Anchorage and Honolulu are to be NAS Stage A Model 2 (FDP)-equipped.
[2] The Great Falls (NOTIP) ARTCC is to be absorbed into neighboring NAS centers.
[3] LRR = Long-Range Radar, radar beacon equipped.
[4] 170 VORs to become VORTACs; 70 more to be DME-equipped; 135 VORs to become precision VORs (PVORs).

TABLE *26.-FAA* plans for communications *F&E, FY 70 lo 79.*

Terminal and en route communications facilitiess	FY 69 unit costs dollars)		Inventory (number)		Planned F&E investment. FY 70-79 (millions of dollars)
	F&E	M	FY 69	FY79	
Air-ground voice:					
RTR (terminal)	85.2	8.0	761	1685	9.5
RCAG (en route)	30.0	13.1			
RTR & RCAG improvements	-	-	-	-	36.7
Electronic voice switching systems	na	na	0	105	129.4
Digital data transmission systems	na	na	0	231	0.7M
CAS master time ground stations	na	na	0	65	19.5M

the 1969 level) during this l0-year period for en route and terminal controllers alone is approximately $1 billion. The costs of acquiring and training these additional people is not stated. Since salary costs will not remain constant this understates the costs

The actual additional salary costs approximntely equals the planned investment in facilities and equipments over the same period.

3.4.3 Third Generation System Requirements

Data Acquisition System

Increasing aircraft densities, independent IFR approxhes to close spaced runways, implementation of an IPC and ATC data link service set the

TABLE *27.-FAA positionstaffing plane, FY 70 to 79.*

FAA program	Number of positions		FY 79 / FY 69 ratio
	FY 69	FY 79	
Operations:			
En route centers	8,940	16,500	1.84
Terminals	7,598	16,700	2.2
Flight service stations	4,534	4,534	1.0
System maintenance	9,138	13,300	1.46
Flightstandards	1,194	1,100	.92
Airports	573	600	1.04
Facilities and equipment	1,243	1,500	1.20
Research and development	1,183	1,500	1.26
Total	34,403	55,734	1.62

NOTE.—Estimates are subject to a general review of the FSS program now underway.

TABLE *28.-En route (controller) work force salary costs.*

Element	1969	1979	Increase factor
ARTCC total operations	20.9M	41.4M	1.98
En route (controller) work force (official FAA estimate)	8940	16,500	1.84
En route (controller) work force (no productivity increase)	8940	17,700	1.98
Controller salaries	125M	231M	1.84
(Constant dollars at 14K)		247M	1.98

requirements for the data acquisition system. Safety monitoring of simultaneous approaches to close spaced parallel runways has been examined.[21] The data acquisition system measures aircraft position and measures or compares the velocity both across and along the track to detect deviations from desired interaircraft spacings. Several methods of determining the cross-track rate have been investigated.

The criteria for determining when a command should be given to return to the desired track is a combination of cross-track rate (away from the approach course centerline) and the distance of the aircraft from the buffer zone between the approach courses. When large cross-track rates are detected, the monitoring program would, in addition, examine the adjacent. track to determine whether the recovery maneuver could be achieved without interference to traffic on that track or whether a go-around order must be given. If position data only is available from the upgraded ATCRBS, an unsmoothed accuracy of 100 feet is required to permit computation of aircraft heading to the accuracy requirecl. The false alarm rate was higher than that associated with a method that was capable of deriving both position and velocity data directly. Positionnl accuracies of 100 to 200 feet and velocity measurement accuracies of 5 to 10 knots produced an acceptable monitoring system. Both methods examined assumed a data rate of one measurement per second.

Increasing densities of aircraft will cause a degradation in ATC system performance because of a progressive increase in garbling of identification and altitude data transmitted by the aircraft. While the present. automation systems are able to track aircraft fairly well in the presence of code-train overlap and garble conditions, difficulty has already been encountered in obtaining reliable pressure-altitude data from the aircraft. under these conditions. As traffic densities continue to increase and multiple code-train overlaps occur, the accuracy with which the position of an aircraft can be determined will be reduced. In addition, the ability to decode data transmitted by the aircraft will be similarly degraded.

Since the data rate and accuracy requirements are increasing, the Committee believes that the present. spatial roll-call system is inadequate for the future system requirements in high-density areas and recommends the use of a time- or range-

[21] See Appendix E4—Data Acquisition System Error Considerations.

ordered, discrete identity roll-call type of system to virtually eliminate the garbling problem. The time-ordered, discrete roll-call type of system is inherently a data link as well as position-determining system. The addition of the message to the identity call provides the up-data link to the aircraft for the IPC and ATC services. Similarly, addition of air-generated messages to the altitude data sent by the aircraft in reply to the ground call provides the down-data link to the ground system. The rate at which data are exchanged for ATC and IPC services is one or two orders of magnitude lower than the rate required for position determination. The use of the roll-call surveillance system, however, provides the short access time required by the IPC and ATC functions.

Dnta Processing and Display

A computer sizing group was formed by the Committee to determine the magnitude of the processing workload associated with the automation of the ATC function. The functions estimated include management of the data acquisition system roll-call process; determination of aircraft position using trilateration techniques (this method was selected since it represented the highest computer workload of all possible data acquisition techniques) ; conflict-detection and collision-avoidance, including IPC services: the ATC function including flow control, terminal scheduling, metering, sequencing, and spacing: flight, data processing; interfacility communications: and display generation and controller input, processing. The estimates were made based on a traffic increase of ten times the 1968 values, which are twice the 1995 forecast. The report indicates that the projected computer technology of the middle seventies xvill be adequate for the computer hardware complex necessary to support a ten time increase in traffic.. The complexity of the software was not explicitly addressed beyond that necessary to estimate the size of the computer. Nevertheless, the group concluded that a high level of automation could be achieved by the early eighties. A summary of the group's estimates is included in Table 29.

There is some uncertainty with respect to the total multiplier appropriate to apply to the basic instruction rate. A factor of 12 is used in Table 29 and this is believed to represent a conservative point of view. The majority of the computer sizing group felt a factor of six was more appropriate. Furthermore, the data acquisition system used in

TABLE 29. -Instruction rate estimates *(based on twice the 1996* **Traffic estimate** *for high-density areas).*

Function	En route	Terminal	Central Flow Control
GCAS[1] (mixed airspace, IPC)	2.56 x 10^5IPS[2]	15.1 x 10^5IPS	..
GCAS (positive controlled airspace)	9.2 x 10^5IPS	(3)	
Data acquisition	27.3 x 10^5IPS	48.9 x 10^5IPS	
Command and control	5.6 x 10^5IPS	14.6 x 10^5IPS	
Other en route functions	29.2 x 10^5IPS		
Other terminal functions		10.0 x 10^5IPS	..
Central flow control	.03 x 10^5IPS	.4 x 10^5IPS	.4 x 10^6IPS
Total	7.39 x 10^6IPS	8.90 x 10^6IPS	.4 x 10^6IPS
With glaser mix degradation	14.61 x 10^6IPS	17.35 x 10^6IPS	0.78 x 10^6IPS
With executive overhead	29.22 x 10^6IPS	34.7 x 10^6IPS	1.56 x 10^6IPS
With hi-level language degradation	87.66 x 10^6IPS	104.1 x 10^6IPS	4.68 x 10^6IPS

[1] Ground Collision Avoidance System.
[2] Instructions Per Second.
[3] (Included in command & control).
NOTES. The Glaser factor (1.95) converts average executed instruction to an equivalent number of fastest possible arithmetic instructions and has meaning only when comparisons are made to manufacturer's rating. The assumed executive overhead and redundancy multiplier is 2.0. The assumed compiler inefficiency multiplier factor is 3.0.

the sizing effort was more complex than the data acquisition system recommended by the Committee. However, by the very nature of such estimates, every factor that can be identified is counted but there usually are unidentified factors.

The upgraded Third Generation System will provide the controller with a display of aicraft position, altitude readout, and readout of computer generated control information. At the option of the controller, the information may be displayed and transmitted automatically by data link to the aircraft. or may be displayed and transmitted only after a controller entry approving or modifying the control has been entered. Control information will continue to be presented until acknowledged by the pilot. Situations of an unusual or emergencv nature will be presented to the controller on his display. Resolution of the problem may require voice contact with the pilot as well as an entry into the computer indicating the action to be taken.

System Reliability Considerations

The current ATC system and its component parts are by their nature a distributed system, and major failures affect a relatively limited percentage of the total airborne fleet. In addition, weather conditions are VFR for a major portion (85 percent) of the time, and pilots can maintain safe separation from other aircraft by operating at reduced airspeed (250 knots) and using "see and be seen" VFR procedures. As traffic densities increase, however, redundancy must. be introduced into the system to achieve a higher level of reliability. Redundant radar coverage is being provided at high-density terminal control facilities in order to be able to operate aircraft at close spacing in trial, and safely survive radar failure. Since loss of primary power has been a fairly common occurrence, critical navigation stations and ATC facilities are equipped with motor generator sets as well as dual inputs from commercial power sources. In the NAS automated centers, an uninterrupted power system is also provided to bridge the time gap between loss of commercial power and start up of the motor generator sets. The automation system being installed has several levels of redundancy, and total failure of the data processing and display system is predicted to occur not more than once in 105 hours. There have been a number of proposals for airborne backup equipment such as stationkeepers and collision-avoidance systems. Before the requirement for such autonomous equipment can be demonstrated, a thorough review of the failure modes and recovery procedures for the current and upgraded Third Generation System must be made. In this type of system analysis, the interactions, multiple coverage, inherent reliability. of the NAS/ARTS equipments, the data acquisition, landing and navigation system, and the towers must be considered. The role of the pilot and controller in each recovery mode must be defined carefully. Recovery procedures must be rehearsed and simulated. Only when such a program shows inadequacies in the recovery modes for various types of system failures is it reasonable to specify additional independent airborne aids as mandatory equipment.

4. THE RECOMMENDED UPGRADED THIRD GENERATION SYSTEM: FACTORS AFFECTING THE SYSTEM CHOICE

The Committee, in selecting the design approach for the Upgraded Third Generation ATC System, recognized the urgency of increasing terminal capacity. This led to the recommended use of close spaced parallel runways on existing airports and precision control in terminal airspace. Of the several ATC system alternatives evaluated, the most effective design for high capacity utilized centralized computation of ATC commands. Systems based on an exchange of data between aircraft could not provide the precision required to achieve high terminal capacity. Thus an approach oriented toward cockpit management is not useful in a high density terminal. Furthermore, the Committee concluded that there was no clear requirement for a system that exchanged data between aircraft.

Selection of the system approach was based on meeting requirements and if possible achieving a degree of compatibility with the present system. Examination of the current system indicated that many of the requirements could be met by implementing improvements to NM-ARTS and ATCRBS. In several areas, however, the Committee found it necessary to recommend new developments. These include improving the accuracy and reliability of the aircraft position data, incorporation of a digital link into the data acquisition system, implementation of Intermittent Positive Control Service and other higher levels of automation than currently contemplated.

The rapid traffic growth and increasing demand for control service suggest that there should be less dependence on manual control methods. The level of automation must increase if the number of aircraft per control team is *to* increase. Automation requirements can be met for sometime in the future by expanding ARTS and NAS and then by the addition of automatic IPC.

Increases in traffic density and reductions in inter-aircraft spacings will also require increased reliability in the air-ground-air and ground-ground data links as reaction times in potential collision situations become shorter. Further, simultaneous independent IFR approaches to close spaced runways require both greater accuracy in position determination and higher data rates in order to adequately perform the safety monitoring function *in* the final approach area. The design of the Data Acquisition System (DAS) for the 1980's must provide for these factors. Many terminal area sites are poor and the multipath interference is great due to the presence of large hangars and buildings in close proximity to the airport. Hence, the Committee selected a directional antenna, rho-theta type of system for data acquisition as it is capable of meeting the accuracy requirements and provides the best protection against multipath interference of all the systems examined. Another advantage of a rho-theta system is that the surveillance function can be accomplished from a single site. In many terminals, it would be difficult to find multiple sites that have the entire departure and en route courses within the field-of-view. Multiple sites are required for trilateration type systems which the Committee does not recommend.

The necessity of reducing synchronous interference problems (garbling) which exist in the present ATCRBS and n-ill become worse as traffic densities increase, led to selection of a range-ordered, discrete identity, roll call type of system operation. This also permits the data link function to be performed as messages may be transmitted with the identity roll call. Similarly, the aircraft replies will include air-ground messages. The data acquisition system design operates in both a roll call or data link mode and a beacon spatial roll call mode to permit. service to be provided to both data link equipped and non-data link equipped aircraft. The data link will transmit limited messages to aircraft receiving IPC service and full messages to aircraft receiving ATC service. The data acquisition and data link requirements can be met by expanding and upgrading the ATCRBS.

Navigation should be based on the continued use of VOR-DME. The capacity and accuracy of VOR-DME seems adequate for the forecast traffic densities through 1995 with incorporation of improvements already developed. Area route navigation will be a requirement in Some transitional and terminal portions of the airspace.

Landing systems for high density terminals should provide 3D curved approach paths to reduce noise, high accuracy for Category III approaches, and stable approach and landing paths which are not affected by poor siting conditions or by the presence of other aircraft. These requirements hare led to the selection of a scanning beam microwave landing system. Consideration should also be given to the inclusion of a cooperative surveillance mode in this equipment to provide highly accurate lateral position information to the final approach safety monitoring function. The landing system requirements can be met by modifications 'to the microwave landing system already under test.

4.1 DESCRIPTION AND OPERATION

The ATC system should continue to be based upon independent surveillance and navigation systems. As in the present system, the navigation is a cockpit responsibility. Area navigation routes will exist in much of the airspace. In the en route area, the pilot desiring IFR service operates in accordance with the ATC clearance and navigates the aircraft in accordance with the clearance. In the terminal area., the pilot follows an ATC-assigned terminal route appropriate to the assigned runway and the time-adjustment required to assure his arrival at the runway with proper spacing. In the final spacing area, the ATC system may modify his route by vectoring and speed control for final time-adjustment. The pilot, however, chooses his own final-approach speed to which the system accommodates.

The functions performed by the ATC system are as shown in Figure 19. Flow regulation, performed on a national basis, schedules the flow into and out of high-density terminal and transition areas. The system operates dvnamically in that rates are adjusted to the rates in the high-density areas and makes the necessary adjustments when weather occupies some of the high-density traffic areas. In addition to the overall flow regulation conducted at a national level, traffic density is monitored within the center on a sector basis, and local flow regulation is performed within those facilities. The runway utilization scheduling proc-

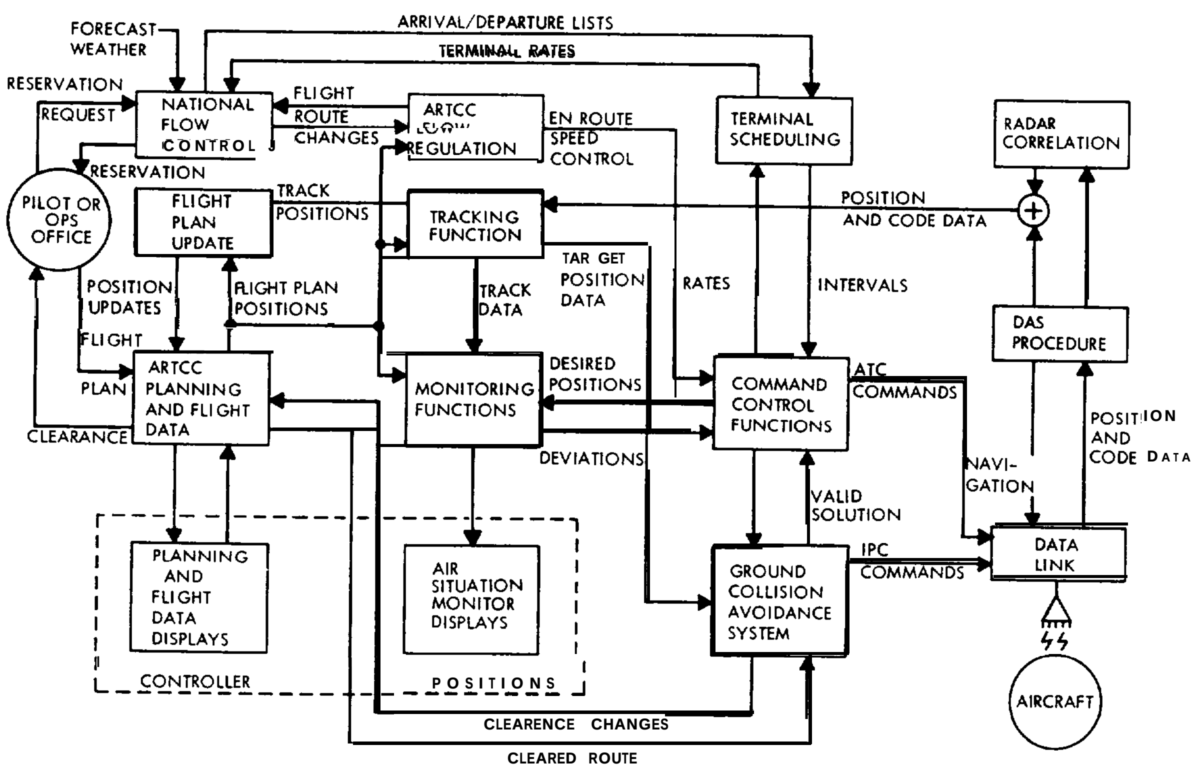

FIGURE 19 ATC system **functions.**

conducted at the terminals exchanges traffic data and flow rates with the national flow-regulation system.

Flight plan processing, updating, flight data distribution, and flight data display are performed by the air route traffic control center for en route and terminal facilities. The filed flight plan is modified, if necessary, and issued to the pilot as a clearance. Once the flight is active, data from the tracking system are used to update the data file on each flight. Route data contained within the flight data file are used by the real-time monitoring function that checks continually for lateral deviations (i.e., deviations away from the route) during the progress of the flight. When such deviations are detected, they are fed to the ATC control process. The flight plan processing function also provides aircraft route data to the collision avoidance function within the computer. These data are used to check for potential conflicts between controlled aircraft and also between controlled and uncontrolled aircraft.

Longitudinal monitoring also is performed as the aircraft progress toward high-density terminals. The control process regulates the flow into these areas in several steps. The first control exercised is national flow-regulation, which adjusts flow rates to terminal capacities. When demand exceeds capacity, that process establishes departure times for all aircraft, which keeps a full load of aircraft in the system but prevents severe airspace overload and lengthy holding conditions from developing. Once airborne, flights proceed at normal en route cruising speeds until approaching the terminal area. The control process normally adjusts arrival rate by speed control in the transition area such that the desired traffic rate is metered through the approach fixes. Holding is minimized under all conditions and eliminated under normal conditions by this type of control. In the final spacing area, aircraft are sequenced and spaced for landing. The longitudinal monitoring function periodically compares the aircraft flight time to the next computing point or fix with the desired arrival time and issues control in the form of path adjustments and/or speed changes. The process acts to reduce continually aircraft arrival time error as an aircraft approaches the runway. The ATC monitoring function also includes a final-approach monitor and alarm system. In order to guarantee safety for IFR approaches to closely-spaced runways, the system maintains close surveillance of the final-approach area. Aircraft position and deviation rate away from track are monitored continuously and, when the combination of these factors indicates an unsafe condition, the ATC system exercises control in the form of an alarm to the cockpit—either commanding the aircraft back to the final-approach course or commanding the aircraft to execute a missed-approach, as appropriate to the situation. In addition to ground monitoring of the final-approach area, it may be desirable to have cockpit displays showing the location of each aircraft in the vicinity making approaches to close-spaced parallel runways in IFR conditions.

Separation between controlled aircraft is achieved by examining the projected flight path of these aircraft extended sometime into the future—for example, 30 minutes. Any potential conflicts that are detected in that period are stored, continuously checked and action to resolve them is taken at the appropriate time. Control is in the form of vectors or altitude changes. Separation between controlled and uncontrolled aircraft is achieved by detection of intruders in positive controlled and mixed airspace as well as detection of encounters between aircraft in mixed airspace. When the system detects that an uncontrolled aircraft is about to intrude into positive controlled airspace, it vectors the aircraft away from this airspace via the IPC data link. In mixed airspace, the uncontrolled aircraft under IPC is assigned a flight intent if a collision threatens with a controlled aircraft. In encounters between uncontrolled aircraft in Mixed Airspace both aircraft are given conflict resolution commands. Whenever a conflict resolution action is required, it overrides the ATC function. In addition, proposed changes in speed, route, or altitude necessary for runway sequencing purposes are checked by the ground collision avoidance function before issuance to the aircraft.

The data link transmits air traffic control separation messages to the aircraft and receives altitude and control-acknowledgment messages in reply. Replies are also used to determine the position of the aircraft. Assignment of aircraft to particular data acquisition sites is by the terminal or en route center computers. The appropriate computer orders the surveillance and data link messages to be transmitted to the aircraft. Processing of the data received from the aircraft consists of deriving the three-dimensional position for each aircraft. Primary radar system tracks are compared with the data acquisition system tracks to locate aircraft whose equipment has failed. The position data are then associated with the appropriate flight plan data.. Data not correlating with a flight plan are transferred to the ground collision avoidance function to be used for the short-term conflict detection and resolution process.

The functions just described represent normal system operation. The design of the future ATC system must consider maintaining safe operation during various conditions of system element failure. During such operation, the system must operate safely but may introduce some additional delay into flight operations. Maintenance of safety has dictated that the following capabilities be included in the design :

1. Duplicate coverage is to be provided in high-density areas and routes by the data acquisition system. Data on each flight in such areas are to be available from either site as designated by the computer in one DAS cycle time.

2. Computer design and operation includes one level of fail-safe operation and graceful degradation following additional failures.

3. System operation following major facility failure (e.g., loss of a center because of total computer outage or power failure) will be maintained by distribution of functions to other facilities and to the cockpit. The degree to which responsibility must be returned to the cockpit will be determined to some extent by the level and reliability of the ground automation system. In the transfer of functions between facilities that follows terminal facility failure, the final-approach monitoring function will pass immediately to the tower cab controllers at each of the affected towers. In addition, the flow-regulation and metering functions will be adjusted to interrupt flow to the terminal area and subsequently reestablish this flow at a lower rate. Transfer of some responsibility back to cockpit will involve following procedural three-dimensional routes to the assigned runway.

The requirements on the data acquisition system can be met by upgrading the ATCRRS to provide improved reliability and accuracy particularly in high-density areas. A data link capability can be added to provide automatic intermittent Positive Control service to uncontrolled aircraft and ATC service to controlled aircraft. In addition to these basic requirements, a supplementary capability may be required in high-density terminal areas to provide accurate aircraft crosstrack velocity on final approach. This is used by the ATC monitoring function to aid in determining when a missed approach command should be generated. If crosstrack velocity is computed from position data, 2 milliradians azimuth and 100- to 200-foot accuracy is required. Since crosstrack velocity is required only in the high-density terminals, it is desirable and may be possible to derive this information from the recommended microwave landing system. Under these conditions the required data acquisition system accuracy becomes 3 mils in azimuth and 100 to 200 feet in range. This approach would permit the phased array aperture to be approximately 35 feet.

The computer capability for the ATC System must be adequate to handle the traffic load forecast for each time period. The computer program should contain the recommended functions required to support the level of automation indicated for each time period. It must provide for automatic recovery from a variety of computer system failures. The hardware selected should be capable of achieving the following approximate execution rates :

	Largest terminal area	Largest en route area
1980	10-20 MIPS [1]	10-20 MIPS.
1995	25-50 MIPS	20-45 MIPS.
Ultimate growth (2 × 1995 traffic)	55-105 MIPS	45-90 MIPS.

[1] Million Instructions Per Second.

This is derived from a study [1] of the computer requirements for a traffic forecast based on one million aircraft., which is twice the predicted 1995 level. The range of required computer capability reflects uncertainties in hardware and software efficiencies.

As higher levels of automation are achieved, direct exchanges of control data between the computer and the airborne systems should be provided by the data link. The information provided to the aircraft should be sufficient to permit coupled flight. The workload associated with each flight would be largely assumed by the automation system. The controller in this environment would monitor the situation as displayed to him, maintain executive control over the system, and handle special flight requests and emergencies. Since the workload per flight is reduced, the number of flights that can be handled by a control team is increased. Controller displays in this time period

1 See Appendix D.

should be of highly processed data presenting in-depth information only on those situations requiring controller intervention.

Normal displays are more of a system status nature, for example, sequence lists of terminal area traffic. Automation of the ground environment should also reduce the workload in the cockpit. Terminal information should be available from voice broadcasts as at present. Control service communications, however, should be by data link and in a form that should permit the pilot to fly coupled transitions and approaches using inputs from the navigation receivers and the ATC data link. Cockpit instrumentation should permit continuous monitoring of the performance of both air and ground systems. Ground or airborne failures should uncouple the system and flights should be capable of being continued using alternate inputs and displays. Automation of the ATC environment permits the pilot to select either the role of active flight control or of aircraft system monitor.

4.2 DATA ACQUISITION SYSTEM

4.2.1 Introduction

The data acquisition requirements for the air traffic control system cannot be met by the existing ATCRBS whenever traffic density is so great as to require close-spaced parallels, IPC, or ATC data links. This is caused by the following factors :

1. Positional measurement accuracies of the present system are not good enough to meet all control and separation requirements.
2. The present system will not meet projected traffic densities in the busier areas because of various forms of overloading that result in data loss and garbling.
3. The data reliability is inadequate to meet the requirements of a system with increasing levels of automation.

Many component and system improvements to the current beacon have been studied and tested, and the overall system improvement that could result from them has been analyzed carefully. The beacon system can be upgraded to meet ATC requirements at least through the traffic densities forecast for 1995 by converting it from a spatial roll call to a discrete addressed system and by utilizing phased-array interrogators. No other system met all requirements of siting, accuracy, reliability, simplicity, and evolutionary gromth.

4.2.2 Evolutionary Implementation

The recommended data acquisition system evolves from the current ATCRBS. It resembles the current system in that coverage would be provided by a network of interrogators operating on a common channel. Replies from aircraft would supply azimuth and range information as well as identity and altitude codes. Most aircraft would be on a discrete address roll call and be sent ground-derived control information. These aircraft could transmit data-link information back to the ground. Some aircraft would continue to use only standard transponders and voice communications. They would be spatially roll-called, as in the present ATCRBS.

The system would be monostatic, measuring position from a single site. A computer at each site would make the system capable of continued operation in the event of central computer failure. Redundant coverage will aid system reliability. The upgraded ATCRBS could be introduced gradually with some of the improvements in as little as 2 years.

Phase I

Improved phased-array interrogators operating only in Mode 3A and C would be added to the present system, replacing existing ones in some cases. They would provide greater angular measurement accuracy and better angular resolution.

Phase II

The new interrogators would transmit and receive two-way data link information, interleaved in time and space with the standard Modes 3A and C interrogations and responses. This data-link information would be addressed discretely to those aircraft equipped with new ATC data-link transponder equipment. This new equipment, together with the new interrogators, will provide the measurement accuracies and reliability necessary in high-density airspace.

Those aircraft still equipped with standard beacons will continue to be accommodated in other airspace and will be controlled by voice instructions as at present. However, in the most dense areas, standard beacon reporting and voice control will not be adequate for two reasons:

1. Voice relay of automatically generated control information will be inadequate because of delays, lack of sufficient radio channels, and the need for too many controllers.
2. The beacon replies would be garbled be-

cause of aircraft densities that greatly exceed the positional resolution of the beacon system.

Aircraft flying in portions of Mixed Airspace may be required to have the Intermittent Positive Control decoder, which mill work in conjunction with their beacon receiver and mill be activated by the ATC computer to furnish guidance for navigation or collision avoidance when necessary. In addition, it will be used to trigger discrete replies from the transponder on that aircraft. Since all these equipped aircraft can be addressed sequentially in a range-ordered manner, there will be no garble, and they can be removed from standard beacon interrogations. The fleet must become equipped with the IPC receivers early enough to prevent standard beacon reply garbling.

4.2.3 Current ATCRBS Limitations

Accuracy

The current beacon system lacks measurement accuracy and has limited traffic capacity and reliability. The current 4 degree beam can be centermarked to an accuracy of 0.25 to 0.4 degree. However, the FAA presently does not use centermarking for separation service because of poor accuracies caused by garbling and reliability.

Range accuracy is currently 370 feet caused primarily by lack of precise delay control in the aircraft transponder system. While these accuracies may be sufficient for some levels of airspace, they are inadequate in high-density areas. Adequate accuracy can be achieved by use of larger interrogator apertures and by tightening the specifications on both interrogators and transponder beacons. If this is done, in conjunction with the discrete addressed mode of operation, a 0.12-degree azimuth accuracy can be reliably achieved. The high accuracy is only required for monitoring close-spaced parallels. If this measurement can be made available from the microwave ILS, as seems possible, then the requirement on the data acquisition system can be relaxed.

Data rates will also affect tracking accuracy, and the current. interrogators are limited to a &second rate (the rotation rate of the ASR radar on which they are dependent). Mechanical dishes, back to back, might yield a S-second rate, but higher rates may require electronic scanning.

Reliability

Traffic capacity and reliability of replies is already limited and will become worse as more aircraft become equipped and more interrogators are placed in service.

Lost Replies

Lost replies are caused by the following conditions :

1. Overinterrogation. Too many interrogators cause dead time in the transponders and decrease their sensitivity.

2. Poor coverage. Interrogators are collocated with ASR or en route radars and, hence, subject to siting limitations peculiar to the radar but not necessarily the interrogator multipath nulls also cause lost replies.

3. Nulls in aircraft antenna patterns. During maneuvers, aircraft antennas are shielded, often causing dropouts. This may require multiple aircraft antenna and receiver installations. On a typical large aircraft with a single antenna installation, approximately 2 percent of the desired coverage region may be occupied by 20-db nulls. Multiple antenna installations may reduce it further to 0.1 percent These multiple antennas would each feed a receiver and the one with the strongest signal would be used to transmit the reply.

Garbled Replies

Garbled replies are caused by:

1. Timing conflicts between widely separated aircraft replying to different interrogators.

2. Aircraft within one beamwidth and within 2 miles of the same range replying to the same interrogator (signal overlap).

3. Multipath reflections that distort the code structures. False replies are caused by spurious reflections from nearby objects such as hangars and often appear at radically different azimuths.

4.2.4 System Improvement Options

The beacon system, an outgrowth of various IFF systems, has emerged from a long evolutionary cycle. Many improvements already have been incorporated. Many more hare been suggested, studied, and tested. Figure 20 summarizes the system problems outlined previously and shows design changes one might make in order to improve performance in those various areas.

Narrow Interrogator Beam

Narrow beams inherently give better angular accuracy and resolution. On reception, the position

	ROLL CALL	NARROW INTERROGATOR BEAMS	RECEIVE MONOPULSE	FEWER INTERROGATORS	RECEIVER SIDE LOBE SUPPRESSION	BEAM AGILITY	BETTER SITING	ELEVATION BEAM-SHAPING	DUAL ANTENNAS ON AIRCRAFT	PRECISE DELAY CONTROL	ALTIMETRY EQUIPMENT IMPROVEMENTS
LOST REPLIES											
OVERINTERROGATION				X							
POOR COVERAGE							X				
AIRCRAFT ANTENNA PATTERNS									X		
MULTIPATH							X	X			
GARBLED REPLIES											
FRUIT	X	X		X	X						
OVERLAP	X	X									
MULTIPATH		X					X	X			
FALSE REPLIES		X					X	X			
ANGULAR ACCURACY		X	X				X				
RANGE ACCURACY										X	
ALTITUDE ACCURACY											X
DATA RATES						X					

‘FIQURE 20.-Suggested improvements to ATCRBS matrix.

of a target in a beam generally can be determined to some fraction of the beamwidth (perhaps 10 to 1 with a good signal-to-noise ratio or even 20 to 1 with “on-boresight” monopulse). A narrow beam is less susceptible to angular errors caused by discrete reflecting objects. Narrow receive beams, of course, mill also receive less undesired “fruit,” assuming adequate receive side lobe levels can be achieved. The price one pays is aperture size, which probably becomes too large for mechanical rotation, in particular when one also requires a high data rate (a 2-degree beam at 1030 MHz requires an effective aperture dimension of approximately 30 feet or a circular array diameter of 35 feet). A second problem is the fact that the combination of a narrow beam and a high data rate results in too few pulses per beamwidth with prf limitations because of maximum range. Electronically steered arrays overcome these limitations by forming multiple simultaneous transmit and simultaneous receive beams as well as by efficiently utilizing all interrogation intervals. These arrays also can have agile beams that can be positioned to interleave data transmissions with interrogations and replies.

Beam center-marking is limited in its accuracy by the number of pulses in a beamwidth, and it is desirable to limit this figure in order to minimize overinterrogations in a dense deployment. An alternative method that could be used during reception of the air-to-ground data-link replies is on-boresight monopulse beam steering, which can be accomplished by electronically steered beams.

Siting and Beam-Shaping

Such a phased-array system should be sited carefully to reduce multipath and reflection problems. Placing the antenna close to the ground can reduce the vertical interference pattern that produces dropouts but may reduce low-altitude coverage. Alternately, very high locations (the top of a skyscraper) may also provide good coverage with relative freedom from multipath interference. Beam-shaping of the vertical fan beam can be accomplished by designing antennas or reflectors with a large vertical aperture. If the beam is shaped to have a very sharp cutoff at zero-elevation angle, relatively little energy will illuminate the ground, and, hence, reflection problems will be minimized. Alternatively, stacked elevation beams might be used, with the lowest beam eliminated at those azimuths where terrain or reflecting objects are a problem, thereby achieving the best low-angle coverage that the local horizon will permit. It appears feasible to construct a circular phased-array interrogator, approximately 35 feet in diameter and 20 to 30 feet high, which will readily yield a 2-degree beam and achieve an azimuth accuracy of 3 mils.

Control Of Interrogation Environment

Overinterrogation problems can be improved by limiting the total number of interrogations in an area. At present, there is much system redundancy. Because of the need for “registering!’ beacon and radar returns, each radar has an interrogator co-located with it. When all aircraft are reporting altitude, a few well-sited interrogators should be able to furnish good coverage, and the central computer then can deliver to each radar a synthetic overlay that has been transformed into the slant-range coordinates of that radar. In this way, it may be possible to eliminate or control the usage of many interrogators; the benefits are illustrated in an ECAC study (Reference 18).

Use of 1600-MHz Band

The three major reliability problems with ATCRBS are synchronous garble (cell overlap), nonsynchronous garble (total fruit), and overinterrogation. We have shown how synchronous garble can be controlled by roll-call interrogating standard beacons. But the control of nonsynchronous garble and overinterrogation must be performed, at least in part, by the ground interrogator environment. This involves closing some installations, turning off others, supplying them with registered information, and equipping all with SLS. Prior agreement of all common system users (civil and military) is essential before serious implementation of the system can commence. This agreement, in practice, may be unattainable for various political or operational reasons, and, therefore, a different approach may be more attractive in the end.

A new interrogator could be designed that would continue to transmit standard interrogations and receive standard replies, but would transmit all roll-call interrogations and messages (both ATC and IPC) on a new frequency in the 1600-mz band. All ATC and IPC replies could be received on a second frequency in this band, thereby providing a garble-free channel for both. Interrogations and replies would be spatially and roll-call addressed as before with a narrow-beam transmission. Angular accuracy should be 50 percent better than at the present frequency for the same aperture size.

It appears feasible to construct a new, circular phased-array interrogator that can operate at both 1000 and 1600 MHz. On the other hand, it is unlikely that existing rotating interrogators cnn be modified to also transmit and receive data at 1600 MHz. This disadvantage in the early stages of systern implementation must be considered carefully.

The cost to general aviation might be somewhat higher since an entirely new beacon (rather than just a new IPC decoder-display) would be required. On the other hand, the IPC replies would no longer be limited to identity and altitude, and this may give the system designers more freedom with regard to IPC acknowledgements or other air-to-ground data.

Another advantage that must be considered is the possibility of better code design for multipath protection. At this point, it is not absolutely sure that narrow beams alone will give the multipath protection necessary for system reliability. A combination of narrow beams and coding certainly bears the lowest technical risk. The remainder of this section describes a system based upon the continued use of 1030 and 1090 MHz. A new system at 1600 MHz, however, would have essentially the same technical features.

Data Link Transmissions

Data link commands to equipped aircraft will be addressed discretely and directed spatially to the particular aircraft. Since the aircraft position is known, the commands can be range-ordered to prevent garble upon reply. Message requirements per interrogator probably will not exceed 2000 messages per second of 50 bits each and can be transmitted in bursts of range-ordered messages interleaved in time with the standard interrogations. The total transmission time requirements of these data will only be a few percent of a1l available time, and, therefore, mill not interfere appreciably with the normal Modes 3A and C functions. Since data-link information is only to be received by specially equipped aircraft, coding can be used that mill lessen the interference in the standard aircraft beacon receivers and minimize multipath interference. The design of this coding requires further study and a multipath measurement program.

The requirement for roll-call interrogation of a large percentage of the aircraft in a dense traffic area (in order to avoid cell-overlap garbling) has been established. Once this provision has been made, the addition of a command message is relatively simple. In the ATC data acquisition, command messages to both ATC-equipped aircraft and IPC-equipped aircraft can use the same message format (although the IPC message may contain less information).

Time-lnterleaving of Messages

A standard interrogator transmits Modes 3A and C interrogations at approximately 400 per second. They each take less than 30 microseconds. The unambiguous range (2500~psec.) is 200 miles. Since the useful range (consistent with azimuth accuracy requirements) is only about 100 miles, one-half of this time can be used for data transmissions. If a command message takes 50-psec., 20 messages could be transmitted each 1/400-second epoch (Figure 21).

If ATC and IPC aircraft initiate a 1000-psec. delay before replying to a command, all replies will occur during the dead time between 3A and C and the start of a message period. Hence, the receptions (either standard beacon, IPC beacon replies, or data-link replies) will all come within the first 1500-psec. period, and the interrogator will not have to receive and transmit simultaneously. Since aircraft in the roll-call are known in range and azimuth, their messages can be trans-

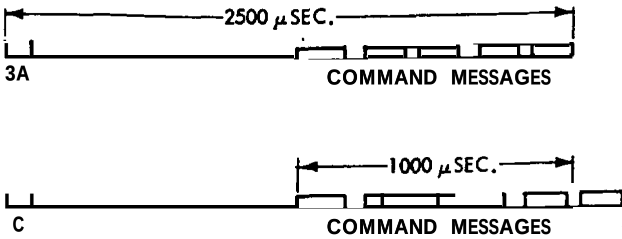

FIGURE 21.~Modes 3A and C interrogations as a function of time.

mitted at the proper azimuth, and range ordered, so as not to conflict with each other (but also so as not to conflict with standard beacon replies in the case of IPC-generated replies). Hence, garbling because of cell overlap will be eliminated.

However, since random garbling caused by fruit will still be present to some extent on 1090 MHz, it will be desirable to provide a separate air-to-ground channel for data-link replies. If it can be near 1090 MHz in frequency, the added cost of an extra oscillator should be very small (a fixed-tuned power amplifier can be used for standard and data-link replies). Two benefits result:

1. Higher data reliability can be provided to ATC aircraft since all data can be range-ordered, and there will be no garbling in the clear channel.

2. New interrogators can make monopulse azimuth measurements during data-link reception, given higher azimuth accuracy.

When this message interleaving is applied to the new phased-array interrogator, the message transmissions can be repositioned agilely in azimuth from message to message (and the receive beam steered to the right azimuth at the right time)! and the full message capacity can be realized for any number of aircraft at any azimuth.

These message interleaving techniques could be added to rotating interrogators. However, the message capacity would be limited and only adequate outside of dense terminal areas. Rotating interrogators are limited in access time and data rates by their $-second rotation period. It is doubtful if this low access-time is compatible with a ground CAS function. Phased-array interrogators, on the other hand, can provide whatever data rates are required up to their capacity of several thousand messages per second.

Message Content

Messages would be transmitted in a digital code, using a modulation system that would provide lessened interference with standard beacon interrogations from other interrogators and would provide multipath protection. The design of this code requires further study. Message length would probably be 50 bits, allowing for several bits of error-correcting code. A readdress feature would be provided on the ground to permit immediate retransmission upon failure to receive a reply.

ATC Control Information

The transition from manual to automated air traffic control, which is presently getting underway and will continue for many years, seems certain to have an appreciable, perhaps drastic, effect on operational procedures. Changes in operational procedures inevitably will produce changes in the nature, quantity, and general character of control communications between the control function and aircraft. Therefore, it is not practical in this report to specify precisely the number, form, and content of these messages.

4.2.5 A System Configuration

Introduction

Some of the data acquisition system requirements are related to a number of factors that are peculiar to the region in which the system must operate. The factors that influence the system capacity requirements are :

1. Size of the region considered.

2. Number and locations of interrogators deployed within the region.

3. Extent of terminal and en route areas.

4. Traffic flow rates and directions within the region.

5. Traffic densities and time statistics.

6. Mix of VFR and IFR traffic through the region.

7. Characteristics of aircraft within the region.

8. Dependence of traffic flow upon meteorological and other conditions.

It is apparent that there is no typical region from which determinations of the requirements for the entire airspace system can be established. However, the use of a representative region should provide a means for determining the capacity of the system, based upon knowledge of the airspace sector considered, and its relation to the other airspace regions.

The Los Angeles Sector

The Los Angeles Sector was selected as the region for which a preliminary analysis and determination of the capacity requirements for the up-

Table 30.—*Estimated peak IAC, Los Angeles, 1996.*

User	Below 10,000 VFR	Below 10,000 IFR	Above 10,000	Total
Los Angeles Center				
ATC	10	50	290	350
GA	3750	450	1350	5550
Mil.	185	15	150	350
Total	3945	515	1790	6250
Los Angeles Basin—60×120 n.m. (about 10% of center area)				
ATC	....	40	30	70
GA	1200	100	300	1600
Mil.	20	5	5	30
Total	1220	145	335	1700

graded ATCRBS would be made. This sector was chosen because of its relatively high aircraft and airport density. Traffic parameters have been predicted for 1995 in this region. Table 30 show these estimates.

Interrogator Location and Coverage

Figure 22 shows the new interrogator station locations that. have been selected. The new interrogators are represented by the circles having 200, 600, and 1200-foot l-sigma error contours. It may be noticed that nearly redundant coverage is provided by the two new interrogator systems serving, and most closely located to, the Los Angeles International Airport. Also, it should be noted that en route coverage accuracies are obtained over essentially the entire sector.

Traffic Routes and Distribution

A general indication of the traffic-density distribution currently existing in the greater Los Angeles region can be obtained by considering the distribution of en route paths within this region. A

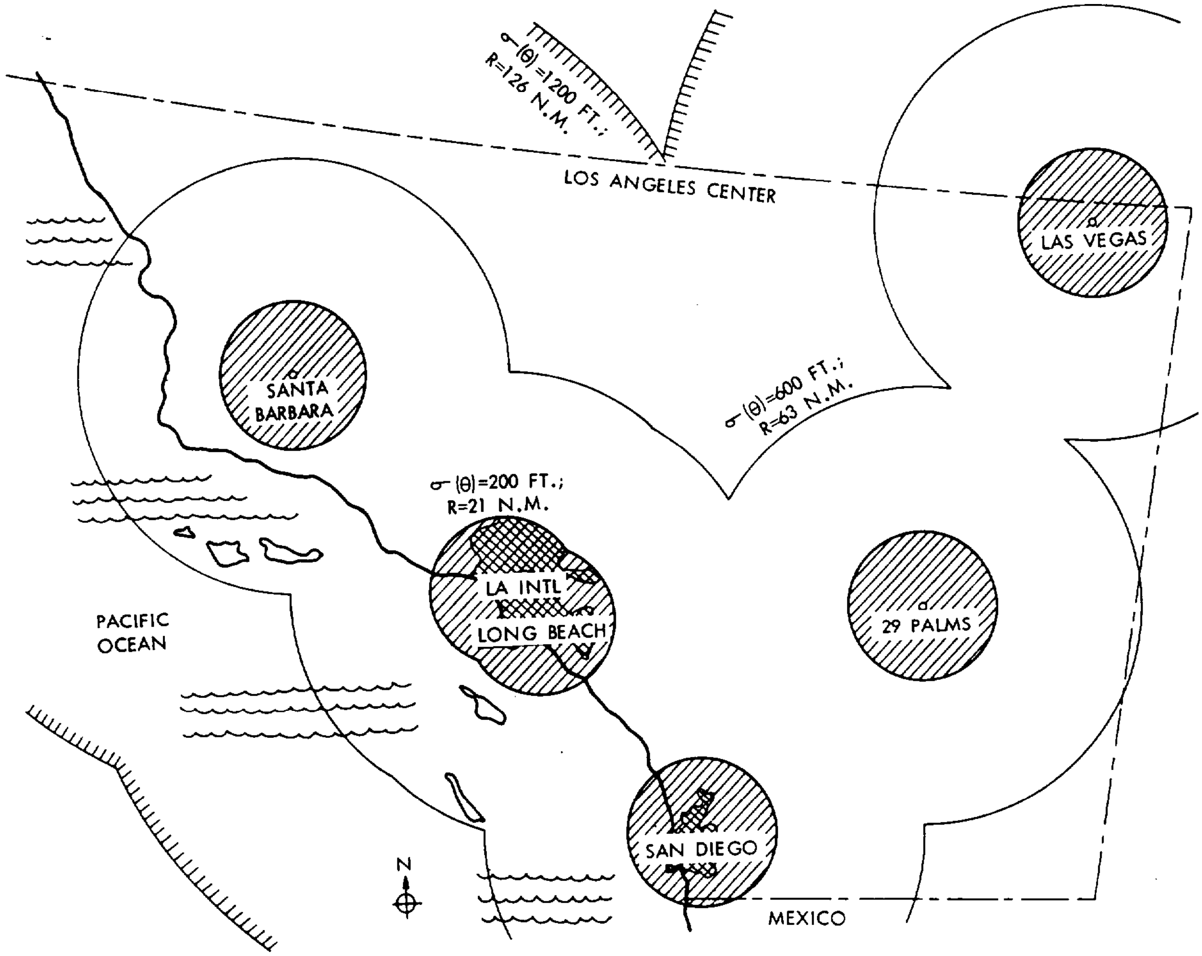

FIGURE 22.-New interrogator coverage for the Los Angeles center.

current distribution of the routes is given in Table 31. The table separates the routing from Los Angeles into four general directions and indicates the VOR route paths associated with these directions. From this, an estimate can be made of the percentage of the traffic distribution in each direction; Additionally, the interrogators located in each routing direction are listed, indicating the relative load that must be handled by each.

interrogation Rate Estimates

Table 31 shows the distribution of traffic along the selected paths. Table 32 provides a breakdown of the interrogation rates for the various categories of aircraft considered, both en route and in the terminal area. Note that each Modes 3A and C interrogation and each ATC interrogation is sent nine times in one beamwidth to accomplish azimuth center-marking on receipt of the nine replies in that beamwidth. It should be emphasized that this analysis is a severe case for two reason:

1. l-second data rates have been assumed for all aircraft within the IPC terminal area to provide high data-rate for ground CAS. It is not clear that all aircraft have to be examined this often. It may be that those aircraft not yet in a dangerous situation can be examined much less frequently, and data rates and CAS computational rates increased when proximity or conflict is imminent. Since this function is a large portion of the total data acquisition, the system load could be reduced drastically.

2. The assumption has been made that all aircraft (even in uncontrolled airspace) are beacon-equipped. If this is not true, the system load will drop drastically, as can be seen from Table 32.

Table 33 distributes these interrogations and replies among the six large interrogators that were placed initially for coverage and accuracy. It will be noted that the Los Angeles, Long Beach, and Santa Barbara sites are loaded to approximately 70 percent. of their capacity for data-link messages (discrete interrogations). The standard beacons reply to more than one interrogator, and hence the total number of replies shown in Table 33 is higher than the number of aircraft so equipped. The Santa Barbara interrogator is overloaded and will be garbled by Modes *3A* and C replies. The implication, of course, is that there must be fewer standard beacons and more IPC beacons in that area for the densities predicted in this time period.

It is possible that the number of replies that must be obtained from IPC and standard transponder-equipped aircraft may be reduced by the use of a monopulse beam-steering azimuth-determination technique applied to the received beacon

TABLE *31.-Current air traffic route distribution for L.A.*

Route direction description	VOR V-design	No. of routes	Approx. percentage of total	Interrogators in routing
North from Los Angeles along coast	V23 V25 V27 V107 V037 V459 V485	7	50	Los Angeles Long Beach Santa Barbara
Los Angeles to Las Vegas	V8N V21	2	15	Los Angeles Long Beach Las Vegas
Los Angeles to San Diego	V23 V25	2	15	Los Angeles Long Beach San Diego
East-west	V16 V208 V264	3	20	Los Angeles Long Beach 29 Palms San Diego
Totals		14	100	

TABLE *32.-Los Angeles Sector interrogator and reply rates.*

Mode	Number of aircraft	Basic data rate	Accuracy (feet)	Discrete interrogations per sec.	Data link replies/sec.	Discrete beacon replies/sec.	Standard beacon replies/sec.
Terminal							
ATC and Mil.	100	1/sec	100-300	100	100	0	0
GA (IPC)	1200	1/sec	100-300	9×1200	0	9×1200	0
GA (Uxc)	400	¼ sec	600	0	0		9×100
Total				10900	100	10800	900
En route							
ATC and Mil.	700	1/sec	600	700	700	0	0
GA (IFC)	4000	¼ sec	600	9×1000	0	9×1000	0
GA (Uxc)	1500	¼ sec	600	0	0	0	9×375
Total				9700	700	9000	3375

TABLE 33.- *los Angeles Sector inlerrogator coverage and message rate estimates, 1995.*

Interrogator station No.	Interrogator station Location	Type coverage	Traffic coverage for station (percent)	Discrete interrogation rates for each station (per sec.)	Data link replies (per sec.)	Discrete beacon replies (per sec.)	Modes 3/A, C beacon replies (per sec.)
1	Los Angeles	Terminal area	50	5450	50	5400	900
2	Long Beach	Terminal area	50	5450	50	5400	900
3	San Diego	En route	15	1455	105	1350	800
4	Santa Barbara	En route	50	4850	350	4500	4000
5	Las Vegas	En route	15	1455	105	1350	600
6	29 Palms	En route	20	1940	140	1800	600

data. The requirement for nine replies was postulated upon the use of a beam center-marking technique similar to that currently used in ATC radars. However, the use of either a boresight or amplitude-comparison monopulse approach appears to have the potential for providing acceptable accuracies and clearly offers a significant improvement in the system capacity and data rate.

The performance of the monopulse system in the presence of garbling and multipath effects should be analyzed and evaluated carefully, possibly including an experimental program, to assure the feasibility of the technique. There may be serious limitations in the approach that are not evident at this time; however, the '(pay-off" in system data capacity obtainable through the use of the monopulse measurement appears to justify a significant effort toward its development. It is a particularly effective technique when all aircraft are discretely addressed.

The actual improvement obtainable based upon the Los Angeles Sector esample may be determined easily by assuming three replies in lieu of the nine indicated in Table 32 for IPC and standard beacon-equipped aircraft. This results in effectively reducing the interrogations and replies by a factor of three. The interrogation rates and beacon reply rates associated with each of the six stations listed in Table 33 decrease substantially. The maximum load for the terminal area stations (Los Angeles and Long Beach) decreases from 5450 discrete interrogations per second to 1850, a change ranging from about 70 percent of station capacity (approximately 8000 interrogations or replies per second) to about 25 percent of capacity.

Message* Data *Rates

Table 33 shows the interrogation rates in the system; the message rates, of course, are much lower. In order to develop a maximum case, assume that:

1. All ATC aircraft are sent messages from the center an average of every 10 seconds.

2. All IPC aircraft are sent messages from the center an average of every minute.

3. All tracking is done at the center and, therefore, all data acquisition is sent at the basic data rates. This implies that all discrete interrogations must be initiated at the center since the interrogator must be informed at what azimuth and range to make the next interrogation.

Therefore, the basic interrogation message consists of :

Identify	13 bits
Azimuth (steering)	10 bits
Range (steering and ordering)	7 bits
Total	30 bits

The basic data acquisition reply consists of:

Identify	13 bits
Azimuth (measured)	14 bits
Range (measured)	14 bits
Altitude	12 bits
Total	53 bits

Since the data-link message rates are low compared to the basic interrogation and data acquisition rates, the foregoing numbers approximately represent the total system load. For the most heavily loaded Santa Barbara interrogator, the data transmission requirements are

$$\frac{\text{from the center}}{4850 \text{ X } 30} = 145{,}500 \text{ bits/sec.;}$$

$$\frac{\text{to the center}}{8850 \text{ x } 53} = 469{,}050 \text{ bits/sec.}$$

If local tracking and roll-call generation were provided at the site, the data rate from t.he center would decrease, and obviously this is desirable in order to provide continued data acquisition in the event of center failure.

4.3 AUTOMATION

4.3.1 Introduction

It will be the goal of the upgraded Third Generation System to establish a highly automated ground-based system that will move air traffic safely and efficiently. The automation recommended is appropriate for each airspace category specified in section 3.3. While automation of the separation service is provided in all airspace (except uncontrolled airspace) flow control, metering, sequencing, and spacing are provided in en route and terminal high-density airspace.

ATC Facilities

Figure 23 shows the basic division of the control functions between the separate ATC facilities. The Central Flow Control Facility will adjust the flow into and out of high-density airports on a national basis. It will accept reservations and maintain a dynamic list of all IFR aircraft with reservations that operate into and out of high density airports. It will adjust the flow rate based on the actual and predicted capacity of the high-density airports. If SST's are introduced for transcontinental service, then it may become advisable to add additional en route facilities to control the high-altitude airspace (i.e., above 45,000 feet). Finally, there is oceanic control to cover the North Atlantic, Caribbean, and Pacific Oceans. This control could be oriented around satellite systems that would combine voice communication, navigation, data link, position determination, and international communications between national ATC systems. Air Route Traffic Control Centers are responsible for the control of all nonterminal airspace (Section 4.3.3). They provide the basic communication network between all facilities and maintain a complete data base on the flight plans of IFR aircraft. Flight service stations serve as the focal point for the entry of general aviation flight plans and reservations. Finally, four classes of controlled terminal facilities are planned:

1. High-Density Metroplex (e.g., New York, Washington, San Francisco, Los Angeles, Chicago);
2. High-Density Terminal (e.g., Atlanta, Boston, Miami, Detroit, Philadelphia, Dayton);
3. Medium-Density Terminal (e.g., Seattle, San Antonio, Norfolk);
4. Low-Density Terminal (many).

The deployment of automation to a given terminal area depends upon the density of traffic.

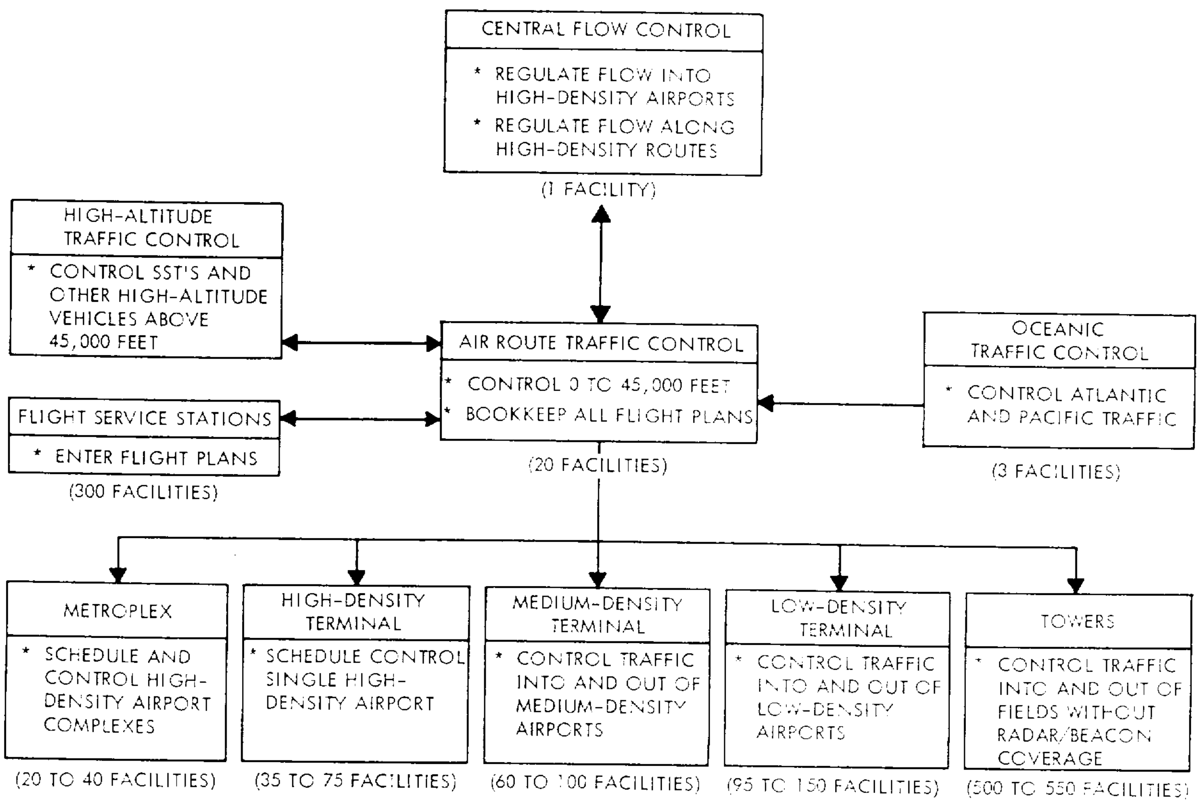

FIGURE 23.—System facilities.

Section **4.3.2** discussed the automation to be introduced in the high-density terminal areas.

Airspace Categories and Functional Services

Figure 24 is a schematic of en route airspace for a future ARTCC. High-density area navigation routes are embedded in Positive Control Airspace. These routes can be moved during severe weather conditions. Traffic flows in only one direction along a route; return routes are at other altitude levels. The ground-based system is responsible for metering the flow along the route, scheduling and sequencing aircraft on each route merging aircraft into the routes monitoring the spacing between aircraft along the route, and issuing speed and passing commands to maintain safe spacing. The system monitors aircraft in the Positive Control Airspace so that they do not intrude into the high-density routes.

The ground-based system projects the present position of each aircraft into the future, based on the present flight plan and track information. It determines whether a potential conflict is likely to occur in the near-term or the long-term. Near-term conflicts are to be resolved by issuing commands such as a heading change, speed change, or altitude change. If a long-term projection of the aircraft flight plan indicates a large number of potential conflicts, then a new route or altitude clearance is determined, and the flight data file amended.

In Mixed Airspace, the system provides separation assurance between IFR aircraft through the same ground-based collision avoidance function described for Positive Control Airspace. The systern contemplates the use in an upgraded ATCRBS of data link associated with the data acquisition svstem for all IFR and VFR aircraft. Their capability can be used in different, ways in different portions of Mixed Airspace.

The system could issue commands to IFR and VFR aircraft to avoid collision. It could issue commands to mark the boundary of segregated controlled or uncontrolled airspace (VFR Highways) as well as one boundary between Mixed and Positive Control Airspace. Until there is widespread implementation of the upgraded ATCRBS, any unauthorized use of Positive Control Airspace and Mixed Airspace by unequipped aircraft is monitored by radar tracks correlated against

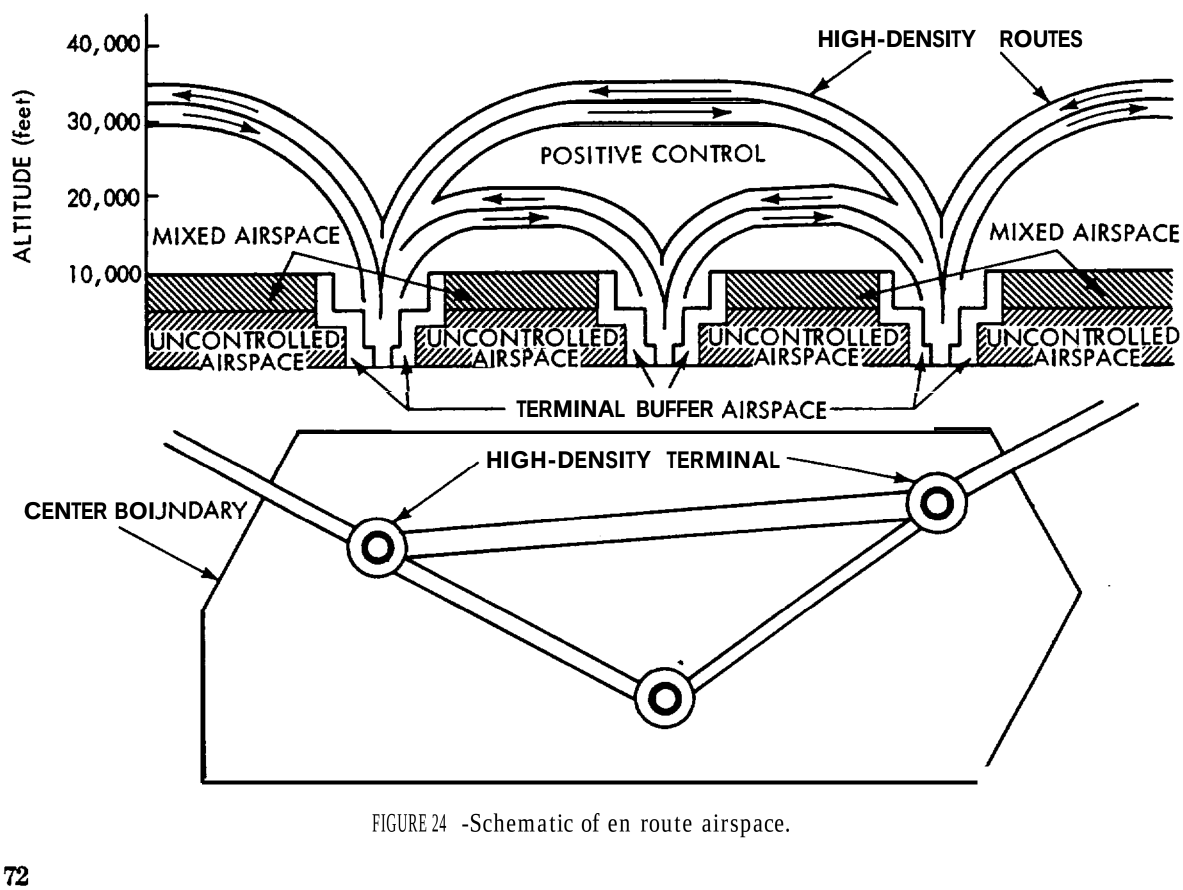

FIGURE 24 -Schematic of en route airspace.

beacon data. In case of hazard, collision-avoidance commands are issued to avoid the intruders.

Figure 25 is a schematic of a high-density terminal area. High-density routes embedded in Positive Control Airspace feed the primary runways. Similarly, high-density departure routes deliver departing aircraft to the en route system. In the terminal high-density airspace, the ground-based system meters the flow onto each runway, provides conflict-free descent commands, issues speed and heading commands for precise spacing on the final approach course, and monitors the longitudinal and lateral spacing between aircraft on close-spaced parallel approaches. Section 4.3.2 describes in more detail the functions performed by the terminal control system in high-density airspace. Aircraft not equipped to receive high-density service may land on secondary runways at high-density airports.

Table 34 summarizes the automated functions provided in the different terminal areas. A High-Density Terminal area mill include all categories of airspace. A Medium-Density Terminal Area is assumed to have all but high-density airspace, and a Low-Density Terminal Area would only have Mixed and Uncontrolled Airspace. The functions described in 4.3.2 are listed in Table 34, and their applications to aircraft in different terminal areas and airspace categories are indicated. It is expected that final spacing commands will be provided at Medium-Density Terminals. The tightness of control and the sophistication would not. bc as high as that provided in the High-Density Terminal Areas.

Man-Machine Relationships

In designing an automated ATC system, it is necessary to decide which functions the automated system can do best and which ones are best performed by the air traffic controllers. Functions that controllers typically should perform are:

1. Monitoring the traffic situation, including the effects of computer-generated commands.
2. Resolving emergency situations for which the computer is not programmed which might, for example, be caused by the failure of airborne equipment and intrusion of unauthorized and unequipped aircraft.
3. Coordinating with other control positions and facilities the reallocations of resources such as airspace and areas of control.
4. Informing the computer of new resource allocations and availability (arrival routes, runways, etc.).
5. Informing the computer of the need to reroute traffic because of runway reversals, weather conditions, navigation aid failures, etc.
6. Informing the computer of landing system failures, runway blockages, etc.
7. Informing pilots of ground equipment failures and the need to invoke a failure procedure.
8. Informing the computer to increase aircraft spacing in order to account for weather conditions such as slippery runways, wind gusts, etc.

4.3.2 Terminal Control

The high-density terminal facility performs the functions shown in Figure 26. The terminal control system can be divided conceptually into the following control areas:

Transition control--This control process brings arrival aircraft down from en route or intermediate altitudes and feeds the approach control area at a metered rate. This process controls

TABLE 34.-*Automated terminal functions.*

Functions	Highdensity terminal				Medium denslty terminal			Low-density terminal	
	HDA	PCA	MA	UA	PCA	MA	UA	MA	UA
Automatic tracking	X	X	X		X	X		X	
Flow metering	X	X			X				
Firm scheduling	X	X			X				
Final spacing commands	X	X			X	X			
Departure commands	X	X			X				
Data link commands	X	X	X		X	X		X	
Local control commands	X	X			X				
Final approach monitoring	X	X							
On-line wind measurement	X	X			X				
Intruder detection	X	X	X		X	X			
Collision avoidance	X	X	X		X	X		X	
Automatic rerouting for runway reversals	X	X			X				
Automatic weather rerouting	X	X			X				

HDA = High Density Airspace, PCA = Positive Control Airspace, MA = Mixed Airspace.
UA = Uncontrolled Airspace.

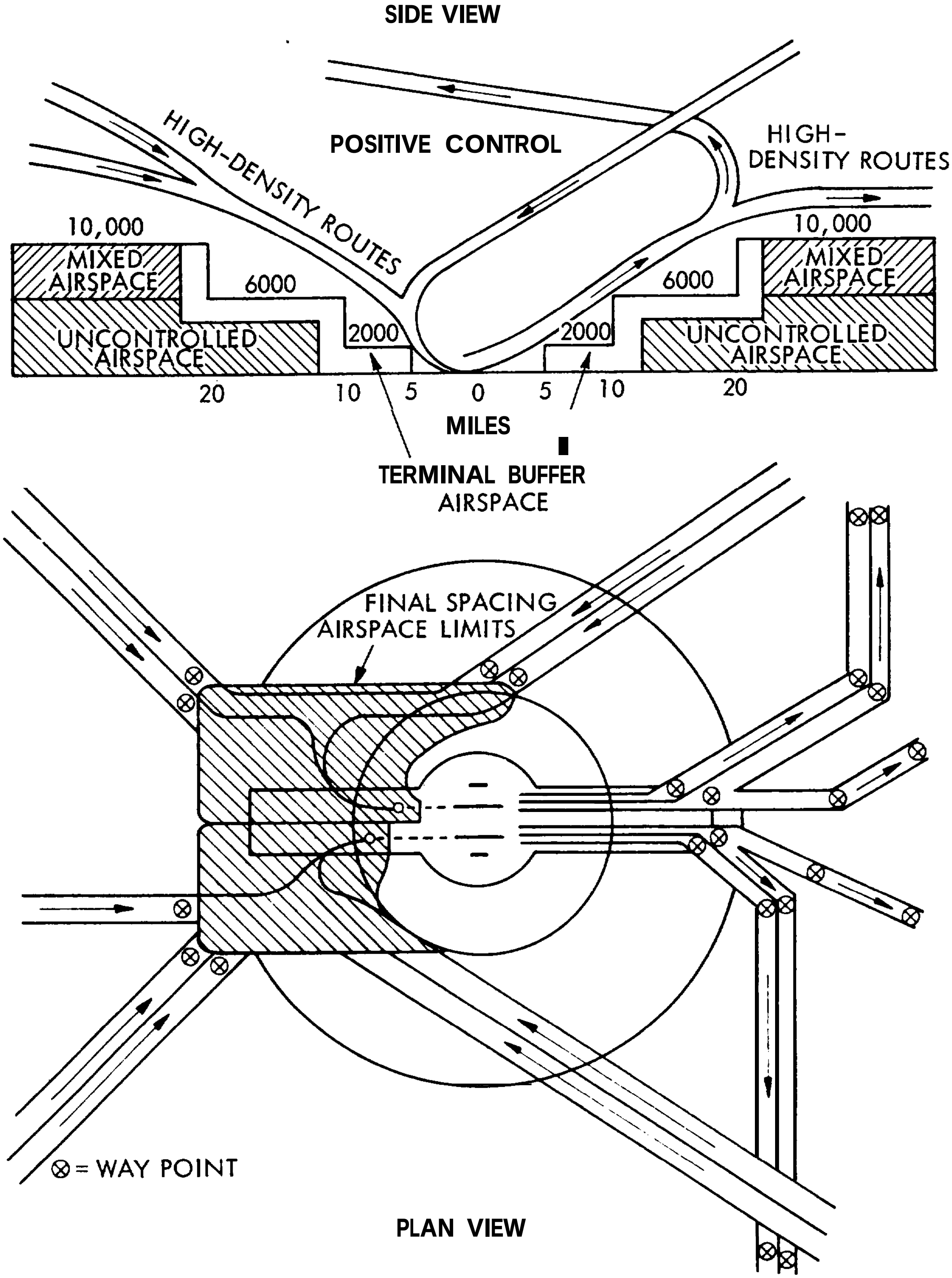

FIGURE 25 -Schematic of high-density terminal area airspace.

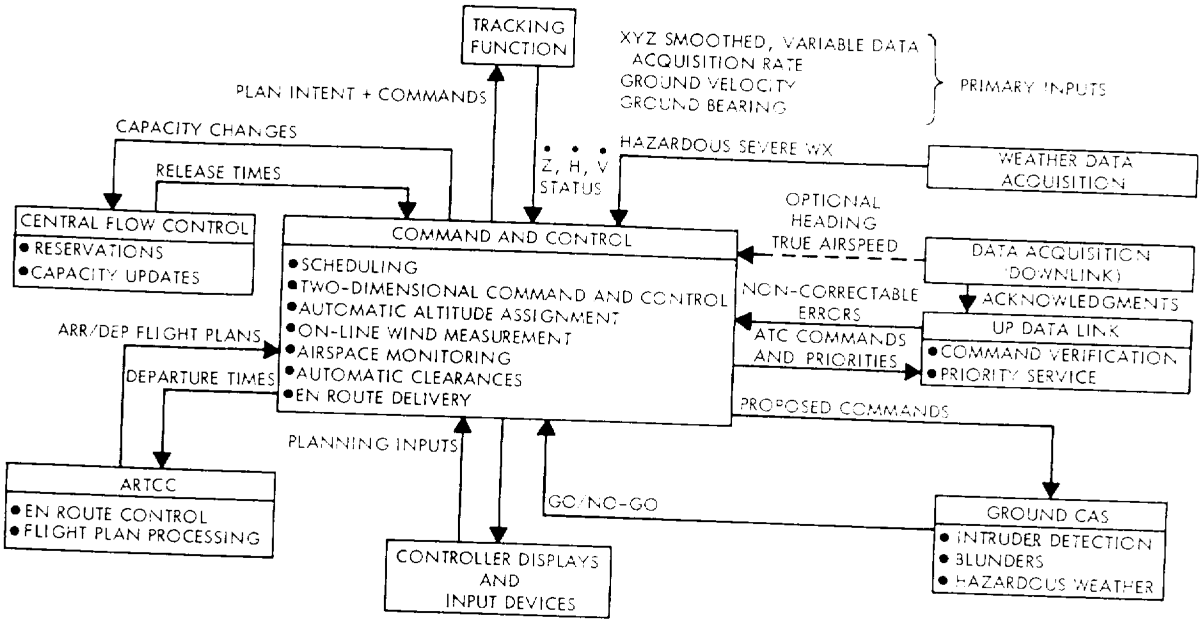

FIGURE 26.—Terminal command and control.

an area from 25 to 90 flying miles from touchdown.

Approach control—This control process delivers aircraft to their assigned final-approach course or landing system properly spaced for their landing. This process is sometimes called final spacing and controls from 4 to 25 miles from touchdown.

Local control—This control process is responsible for the control of the runway surfaces and the monitoring of arrival aircraft along the last 4 miles of flight.

Departure control—This control process is responsible for the control of departing aircraft from shortly after takeoff until their handoff to the en route system.

The upgraded Third Generation System accomplishes the following in the High-Density Terminal control areas:

1. Automatic tracking of all aircraft in controlled airspace.

2. Metering the flow of aircraft into high-density airports by the assignment of runways and routes.

3. Firm scheduling of arrival times at control points for both arrivals and departures.

4. Issuance of speed, heading, and altitude commands to deliver arrival aircraft precisely to their assigned runway.

5. Issuance of speed, heading, and altitude commands to deliver departure aircraft to the en route system at desired time, fix and altitude.

6. Issuance of commands for positioning and release of departures.

7. Monitoring the longitudinal and lateral spacing between aircraft approaching the high-density airports on close-spaced parallels.

8. Dynamically measuring the winds aloft along routes and along the final approach course.

9. Monitoring of controlled airspace for the appearance of intruders.

10. Issuance of collision-avoidance commands.

11. Automatic rerouting of traffic because of runway reversals.

12. Rerouting of traffic to avoid hazardous weather.

13. Automatic transfer of data between the terminal facility and the automated ARTCC and Central Flow Control facility.

The foregoing list of automated functions is a summary of the type of functions to be performed by the ground-based terminal control facility. The following paragraphs mill describe in more detail these functional requirements.

Automatic Tracking

The automatic tracking smoothes and predicts the position and smoothes the velocity. The tracking function receives inputs from the command and control function whenever a new speed heading or altitude command is issued. These inputs are used to adjust the smoothing parameters based on the command. Whenever there is a loss of data from one or more of the primary data acquisition sources, the automatic tracking function selects the best alternative data source.

Metering

The metering function balances the flow of aircraft into the terminal area so that the flow rate to each runway is less than, or equal to, the capacity. The metering function tentatively schedules aircraft to land on specific runways at specific times. It also assigns routes to fly to the assigned runway.

The metering is performed as aircraft enter the transition control area and provides a basis for the control program to issue delaying maneuvers when the difference between the aircraft's estimated time of arrival and the desired time of entry into the approach control area exceeds the possible correction in the approach area. Delaying maneuvers include speed reductions, path adjustments, and/or holding.

Firm Scheduling

Before entering the approach control area, a firm schedule is drawn for all aircraft. The scheduled landing interval between aircraft is based on such factors as the minimum separation standard along the approach course, the individual aircraft speeds on final approach, the runway occupancy time: the length of the final-approach course, the system performance (ability to control the delivery of the landing system and runway), the variability in aircraft speed because of pilotage and instruments, the minds and mind variability, the constraints of make turbulence, the capability of ariborne equipment, and the desired arrival/departure ratio. Other factors such as interarrival runway-dependence and runway orientation may be included, depending upon the complexity of the ground and air environment.

When an aircraft is late and cannot meet the scheduled interval, the scheduling function routes the aircraft along the shortest path. The scheduling function is dynamic; it seeks to slip the schedule forward by control action whenever slack exists. It also slips the schedule backwards whenever an aircraft has missed a command and cannot make up lost time. Finally, the scheduling function automatically resequences aircraft that have blundered or have missed approaches. The scheduling function assigns departing aircraft to runways and routes based on aircraft type, release times (supplied by central flow control), noise abatement procedures, and terminal gate positions.

Arrival and Departure Conflict-Free Commands

Throughtout the terminal area, aircraft landing on high-density runways are issued conflict-free commands for changes in speed, heading, and altitude. In the transition control area prior to the approach fix, the commands consist primarily of altitude descents on area navigation routes. After the approach fix, heading and speed commands are used in conjunction with coded area navigation routes to provide spacing control. A final time-correction is achieved by an early or late reduction in final-approach speed. The system allows each aircraft to specify its desired final-approach speed. The terminal system continously predicts the touchdown time of the nest arrival on each final-approach course and issues control commands to position and release departures for takeoff in accordance with predetermined separation standards.

Departing aircraft receive commands in a similar manner to arrivals. If a three-dimensional area navigation route can be assigned at takeoff, then only a monitoring function is required. If a given delivery time to the en route system is required, then a series of speed and path-stretching commands may be used.

Final-Approach Monitoring

The system monitors the longitudinal position of all aircraft on the final-approach course. Whenever the time or distance separation becomes hazardous, it issues speed commands. If speed commands cannot. be accommodated because of aircraft, performance limits. then a missed-approach command is issued to the aircraft.

Whenever there are closed-spaced parallels, the system monitors the lateral deviations and cross-track velocities to determine if an aircraft is making a normal approach. If not, an alert command and a heading change are issued. If the aircraft fails or is unable to heed this command, then a check is made for potential conflicts with any aircraft on a parallel approach. If such a conflict exists the aircraft on the parallel approach is issued a missed-approach command.

On-Line Wind Measurement

In order to control aircraft efficiently throughout the terminal region, there is a need to derive the winds aloft along all control routes. By measuring the difference in ground speed along routes relative to the commanded indicated airspeeds, the ground-based system can derive the effective wind. By averaging over several aircraft, the system can dynamically smoothe and predict the winds aloft at different altitude levels along each route.

Intruder Detection

In order to protect aircraft in high-density airspace, it is necessary to monitor the positive control airspace to determine that aircraft not under positive control do not stray into positive control airspace and, subsequently, high-density airspace. Any unauthorized intruder will be tracked and, if possible, given commands to vacate the airspace. If the intruder becomes a threat to controlled aircraft, then the controlled aircraft will be vectored around the threat. If an intruder is detected without any altitude information, then the system will assume the hazard to exist over all altitudes within the terminal area.

Collision-Avoidance Commands

In terminal airspace, the system monitors the position and velocities of all aircraft in order to detect possible collision situations. appropriate commands are issued as required. In addition, segregated airspace may be used at some terminals to minimize interaction between controlled and uncontrolled aircraft,. The boundaries of this airspace are monitored, and corrective commands are issued as required.

Rerouting for Runway Reversals

Whenever the winds shift to the extent that a change in runway utilization is required, the system accepts inputs from the planning positions to reorganize the traffic for the new runway direction. In a metroplex area like New York, there is considerable interairport interaction. Therefore, the arrival and departure routes for several airports are defined as a group for each wind direction, and the landing/departure patterns are shifted simultaneously for the group of airports.

Weather Rerouting

The upgraded Third Generation System c.an be flexible enough to redefine arrival and departure routes when severe weather traverses the area. It is sometimes necessary to halt the arrival and departure flow until a storm has passed through the area. The central flow control facility is informed of any capacity changes.

Interfacility Data Transfcr

The terminal system automatically exchanges digital information with the Air Route Traffic Control Center (ARTCC) and t.he Central Flow Control Facility.

4.3.3 En Route Control

In Figure 27 there are three areas of en route control identified. This section will discuss each briefly.

Control	Airspace
Air Route Traffic Control Centers.	All airspace in continental U.S. below 45,000 feet eselusive of terminal control facilities
High-Altitude Control-----	All airspace in continental U.S. above 45,000 feet
Oceanic Control-------	All airspace over North Atlantic and Pacific that is adjacent to continental U.S. and through which U.S. air carriers fly

Air Route Traffic Control Centers

Figure 27 is a functional block diagram of an ARTCC and its interfaces. It shows the type of information that is expected to flow between the ARTCC and the other facilities. In addition, it shows the flow of information between the airborne system and the ARTCC. The ARTCC of the upgraded Third Generation System performs the following functions :

1. Accept, process, and distribute flight plan information to the appropriate facilities.
2. Automatically issue clearances to departing aircraft. Reservation times for operations involving high-densitv airports are obtained from central flow control.
3. Monitor the conformance of aircraft to their flight plan and issue control commands when required.
4. Schedule traffic along high-density routes.
5. Issue control commands (speed reductions, reroutes, and holds), based on central flow control inputs.

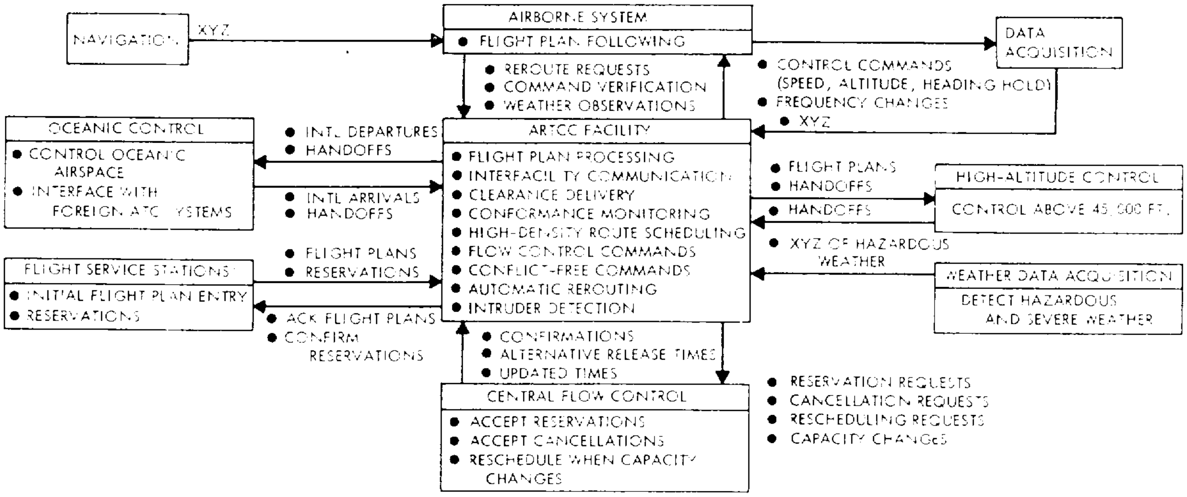

FIGURE 27.—Functional block diagram of ARTCC system.

6. Reroute traffic because of hazardous weather conditions (e.g., thunderstorms and clear-air turbulence).

7. Process data so that all controlled airspace can be monitored for the presence of unequipped and uncontrolled aircraft so that intruder detection and IPC service can be provided.

The following paragraphs describe those functions that are automated in the ARTCC.

Flight Plan Processing

Flight plan processing is still one of the functions of the ARTCCs. However, it differs from today's system in the following way:

1. Reservations are required to and/or from high-density airports. These reservations are filed and maintained by the central flow control facility.

2. Controlled aircraft between high-density hubs are assigned to routes by the ATC system.

3. In order to fly high-density routes, aircraft must be equipped properly (e.g., area navigation, microwave ILS, and upgraded ATCRBS).

4. Filed routes of aircraft not using high-density routes but interacting with them are amended automatically.

5. Localized flow planning is accomplished by determining future workload for each control sector. Whenever the capacity of a given sector is expected to be exceeded, the system automatically reroutes traffic around the overloaded sector or holds flights on the ground.

Automatic Clearance Delivery

The ARTCC is capable of communicating an aircraft's clearance directly to the aircraft rather than through the tower. Before issuing a clearance to an aircraft to or from a high-density airport, the ARTCC checks Central Flow Control for an estimate of the aircraft arrival and departure time. The routing is determined in conformance with flow control estimates. This information is forwarded to the terminal system to control the aircraft.

Conformance Monitoring

The ARTCC monitors the conformance of all aircraft to their flight plans and issues control commands whenever they are required. The conformance checking is flexible enough that if an aircraft or group of aircraft are experiencing favorable or unfavorable winds and their early or late arrival does not result in future conflicts, then the system automatically adjusts the expected arrival times at subsequent control points.

By monitoring the ground speed of aircraft relative to their true or indicated airspeed along their routes, the ARTCC is able to update the effective wind along individual route segments. This effective wind can then be used to recalculate the expected or scheduled arrival times of aircraft at control points along the route of flight.

Flow Control Commands

Whenever the Central Flow Control system is informed by the local high-density terminal system that there has been a significant change in the capacity of a high-density airport, it may issue commands to each ARTCC to revise the departure times of aircraft destined to the affected high-density airport. It also forwards to the affected centers the revised schedule landing times for overflights that are already en route to the high-density airport. When possible, the ARTCC issues speed commands to slow down aircraft en route so that they conserve fuel and reduce terminal congestion. In cases of severe capacity reduction, it may be necessary to place aircraft in emergency holds or diversions in order not to overload the terminal facility.

Automatic Rerouting

One of the more difficult problems that must be faced in an automated system is the ability to reroute traffic dynamically whenever hazardous weather interferes with a high-density route. Thus the system design must be capable of dynamically restructuring high-density routes under hazardous weather conditions. Depending upon the size and location of a storm, the rerouting may require coordination between ARTCCs and possibly the Central Flow Control system.

Restructuring high-density routes appears to be an activity in which the planning personnel and the automated system interact. Man is a good pattern recognizer and more adept at gauging the best means of defining the perturbation in the route, and the computer is best at checking to determine if it is consistent and feasible.

Intruder Detection and Ground-Based Collision Avoidance

These functions, previously described for the terminal area, are accomplished for en route airspace in a similar manner.

4.3.4 Flow Regulation (Terminal, En Route and National)

The upgraded Third Generation System has the capability to provide flow control when necessary. The 30 to 35 high-density airports are linked into a central reservation system. All flights planning to arrive at, or depart from, one of the high-density traffic terminals is assigned a landing or take-off time. The reservation system provides a method for accurately determining traffic demand and for scheduling terminal operations in accord with system capacity.

The reservation system as shown in Figure 28 consists of a single Central Terminal Planning facility. Local Terminal Planning facilities at each

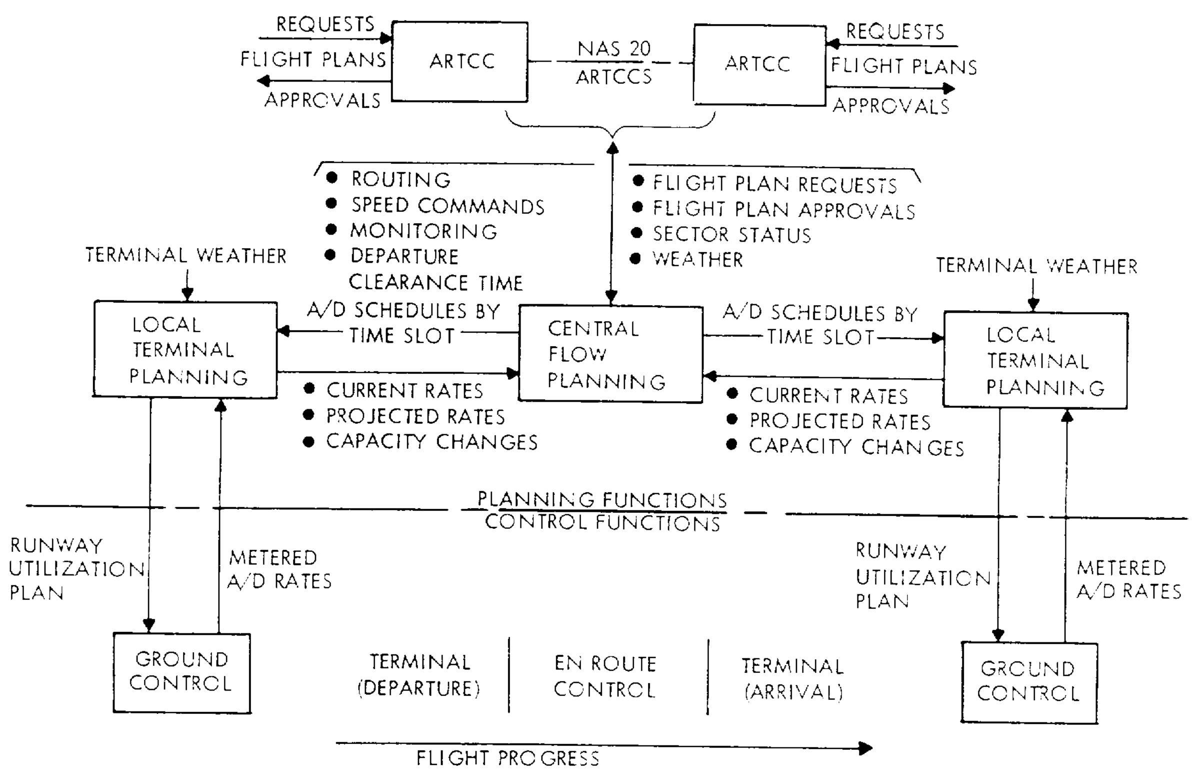

FIGURE 28.—Traffic flow planning and control relationships.

high-density airport, and a number of on-line reservation input terminals located at FSS and at operation offices. Users intending to arrive or depart from the high-density terminal file for a reservation in advance. The reservation request contains information similar to today's flight plan and is entered on an input device that operates in conversational mode. The reservation request is processed by the Central Flow Planning processor. This processor schedules arrivals and departure time slots for all high-density airports. When a consistent set of arrival and departure times is obtained, this information is returned to the user with a clearance time. The Central Terminal Planning facility periodically forwards a schedule of operations to each Local Terminal Planning facility for runway assignment. A discussion of the functions of each planning facility is presented in the paragraphs that follow.

Central Flow Planning

The Central Flow Planning subsystem is the focal point for all flow planning information inputs and decisions. This subsystem will perform the following functions :

1. Allocation
2. Scheduling
3. Flow monitoring
4. Routing

Each of these functions is described in relationship to each other and the overall flow planning task.

Allocation

Allocation is the means by which the total airport operational capacity is apportioned to various users. As implemented in the Central Flow Planning subsystem, the allocation function assigns the number of takeoff and landing slots available on an hourly basis to the various user classes for each of the high-density terminals. It ensures that each user class receives an equitable share of the operations based on current and projected arrival and departure rates.

Scheduling

Scheduling is the process of assigning arrival and departure times in response to user requests. To schedule effectively, the system must accurately predict capacity and demand sufficiently in advance to permit proper flow regulation. Thus, users operating to or from a high-density terminal are required to file a flight plan request several hours in advance of departure. These requirements can be relaxed for certain user classes assuming the terminal and its airspace can accommodate them on a non-interference basis.

One of the objectives of flow planning is to match traffic demand with system capacity. As applied to aircraft arriving at a terminal, the adjustment of arrival rate to match acceptance rate is difficult since an exact sequence cannot be derived in advance. Hence representative traffic mixes are assumed as the basis of planning. The flow control scheduling algorithm establishes approximate arrival and departure times for planning purposes compatible with the aircraft performance, wind and weather conditions, routing, and, of course, user desires. The scheduling objective is to avoid airborne delays. Normally, delays will be absorbed on the ground and the present stacking procedures reserved for emergencies. The approved flight plan that is returned to the user will contain the departure clearance time and a suggested en route speed along with the other flight plan information.

Obviously a schedule is only as good as its input data and assumptions make it. The scheduling algorithm must be able to respond to real-time changes in the input. This implies that there is a means for monitoring flight progress, periodically updating weather, route structure information, terminal status, etc., and revising schedules accordingly.

Sector Monitoring

The sector monitoring function addresses the sector saturation problem in which controller workload becomes the limiting constraint on traffic flow. Certain sectors, particularly the transition sectors adjacent to high-density terminals are sensitive to traffic overloads. These sectors are monitored continuously by menus of a capacity measure. When the capacity measure threshold is exceeded? the sector-monitoring function alerts the routing and scheduling functions to begin diverting traffic to other sectors or to delay takeoffs in the case of departure sectors.

Routing

There are various factors associated with ATC operations that require traffic diversion, e.g., a sudden reduction in terminal acceptance rate, hazardous weather conditions, or sector saturation. The ARTCC's are responsible for providing the rerouting orders to en route aircraft. The routing function in the Central Flow Planning subsystem provides the necessary coordination between ARTCCs and terminals. It is necessary to make decisions on how best to divert traffic, whether to impose ground holds on scheduled departures, or to allow departures and employ en route speed and/or vectoring control.

Local Terminal Planning

At each high-density traffic terminal, a Local Terminal Planning subsystem is provided as part of the overall terminal automation system. The Local Terminal Planning subsystem interfaces with the Central Flow Planning subsystem for reservation functions and coordination of system-wide flow planning. In addition, it schedules the various runway operations. These major functions nre discussed in the following paragraphs.

Inputs to Central Reservation System

For the central reservation system to function properly, each terminal must periodically furnish information on current arrival/departure rates and projected rates for 4 to 6 hours in advance. The actual rates can be determined by suitable metering equipment. One method for projecting the rates is to determine nominal operational rates as a function of runway configuration, type of operation (arrivals only, departures only, mixed), wind direction and intensity, surface conditions, etc. Based on t.his nominal operational rate function, the Local Terminal Planning subsystem can project future capacity from current types of operation, weather forecasts and relevant historical data,

If it becomes necessary to change the operational rate substantially (e.g., because of accident or runway shift), the Local Terminal Planning subsystem notifies the Central Flow Planning facility for flow-planning action.

Runway Scheduling

The arrival/departure schedule that Central Flow Planning provides are a list of aircraft with appropriate flight plan information and a departure time or time of arrival at the outer fix. The objective of the runway scheduling function is to translate this information into specific runway assignments for each aircraft. These schedules are furnished to the terminal control system for sequencing. One critical aspect of runway scheduling in view of the large operational rates is the need for achieving a balance between arrivals and departures. Obviously the Central Flow Planning subsystem in scheduling arrivals and departures must ensure that there is a proper operational balance at each terminal. The task at the local terminal level is to develop a runway utilization plan. This plan will specify the mode of operation on each runway, the time and type of the next mode change compatible with the scheduled operational rates, and other relevant inputs such as the terminal weather forecasts.

The scheduling algorithm used in each terminal computer should achieve maximum utilization of airport facilities by including a small but sufficient time buffer between arrivals to assure a low probability of missed approach. In fact, in scheduling the tentative acceptance rate for each airport, periodic gaps are established to provide for missed approaches and similar contingencies. The frequency and size of such gaps are determined dynamically as a function of such factors as visibility, weather, wind shear, runway configuration and landing instrumentation.

The scheduling algorithm (both terminal and central) also must be able to handle sudden reductions in airport acceptance rates-for example, a runway shift, or an accident on the runway. The local Terminal Planning subsystem is responsible for aircraft in the terminal area, but the Central Flow Planning subsystem in conjunction with the appropriate ARTCC's will divert current. en route traffic to alternate facilities or into appropriate holding modes.

4.3.5 Other Features

Sections 4.3.2 through 4.3.4 have described some of the automated functions of the terminal, en route, and central flow control facilities. The following paragraphs describe some of the system design features that will be common to many facilities, along with the management of the upgraded ATCRBS data acquisition network, the interfacility transfer of data, the weather data acquisition network, the display processing subsystem, and system failure modes.

Data Acquisitin Network

In order to reach the high level of automation planned for the upgraded Third Generation System, it. is necessary to have accurate and reliable data at a high rate. In order to accomplish this,

TABLE 35.-ARTCC communication flow.

Facility	Type of Information
Other ARTCCs.........	Send and receive: Future flight plans plus amendments Progress reports Handoff of control Weather hazards
Central flow control.....	Send to flow control: Reservation requests Cancellations Rescheduling requests Controlling center identification Acceptance rates for terminals Receive from flow control: Confirmation of reservation Alternative reservation choices Up-to-date list of landings and departure times for departures and overflights going to high-density airports Delay en route commands
Flight service stations (FSS).	Send to FSS: Confirmation of reservation Alternative reservation choices Flight plan acknowledgement Receive from FSS: Reservation requests Initial flight plans
Oceanic control.. ...	Send to oceanic control: Flight plans for aircraft departing U.S. Handoff of control Receive from oceanic control: Flight plans for aircraft arriving from outside U.S. via oceanic centers Clearance times for high-density oceanic routes
High-altitude control. ...	Send to high-altitude control: Flight plans for SSTs and other vehicles above 45,000 feet Handoff of control Receive from high-altitude control: Handoff of control Flight plan amendments that affect ARTCCs
Terminal systems....	Send to terminal systems: Arrival flight data Handoff of control Receive from terminal systems: Actual and predicted departure times Handoff of control Acceptance rates

the computer complex must perform the following tasks:

1. Development of a range-ordered roll call for each data acquisition site.
2. Multiple entry points in the roll call for aircraft requiring higher update rates.
3. ,4utomatic retry of unanswered roll Calls.
4. Insertion into roll call of an alternate site when call is unanswered from primary site.
5. Reassignment of aircraft to the roll call of an alternate data acquisition site whenever a primary site fails.
6. Reassignment of aircraft to new sites whenever an aircraft enters a new coverage area.
7. Conversion of data acquisition coordinates into common system coordinates of the control facility.
8. Beam steering of phased-array interrogators.
9. Correlation of upgraded ATCRBS and radar data.

Interfacility Transfer of Data

Table 35 lists information that flows between the ARTCCs and other facilities. In addition, the communications functions include :

1. Automatic error-checking and correction.
2. Automatic retransmission of unacknowledged messages,
3. Redundant communications paths.
4. Alternate routing when all direct communication links fail or are overloaded.
5. Priority treatment of important control messages.

Weather *Data Acquisition Networks*

The weather data acquisition system should provide the ATC system with the following information :

1. Location, size, and predicted position of hazardous and severe weather.
2. Ceiling, visibility, and barometric pressure at controlled terminal areas.
3. Forecast minds (in some areas winds are measured dynamically by the ATC system).
4. Pilot reports on clear air turbulence, storms, etc.

Display Processing

The processing of information for controller display purposes is a major load on the ground-based data processing equipment. The display system provides each air traffic controller with the information that is essential to his area of responsibility. The display normally indicates aircraft positions with limited data displayed to permit controller monitoring of the sector. When the computer detects situations that require control action, the required command to be given to the aircraft will be posted on the display. The controller may elect whether to approve these commands before transmission to the pilot by data link or to permit them to be sent automatically. When the controller detects a potentially dangerous situation, he can request detailed data displays on the aircraft involved.

Failure Nodes Within Single Facility

In order to achieve the high level of automation desired in the upgraded Third Generation System, a very high level of system availability is required. A mean time between system failure of 5 to 10 years is achievable if the following features are provided by the primary system elements (central computer, display subsystem and digital communications, data acquisition subsystem) :

1. Redundant elements and paths between elements ;

2. Automatic error-checking and analysis;

3. Automatic reconfiguration and startover ;

4. Fail-safe computer program modes (operation at reduced capability) ;

5. Automatic recovery recording for fast startover ;

6. On-line maintenance and diagnostics;

7. Multiple power sources and light.ning protectors;

8. Extensive testing of all possible modifications to system hardware and software;

9. Tight control over changes to system software.

One of the most likely causes of system failure is computer programing errors. In order to minimize and/or eliminate such errors occurring in an operational environment, it is necessary to prevent unauthorized changes to operational programs and to test programing changes extensively before introduction into the operational environment.

Catastrophic Failures

Even through a high degree of reliability is designed into each facility, a necessary part of the system design is the inclusion of emergency backup procedures to protect against the catastrophic failure of a complete facility. The upgraded Third Generation System must be capable of automatically backing up a portion of adjoining facilities.

For example, each ARTCC is backed up by three or four adjacent ARTCC's. This requires the following features :

1. Each adjacent center must have knowledge of all IFR aircraft in the areas in which it may have to provide backup.

2. Each adjacent center must have access to one or more data acquisition systems that cover the backed-up area.

3. Each adjacent center must be informed of all control commands, flight plans, and flight plan amendments made to aircraft in its backup area.

4. Each adjacent center must track all IFR aircraft in backed-up areas.

'5. Each adjacent center must have access to a data link system that can communicate with aircraft in the event of failure.

Whenever the failure occurs, the adjacent centers must be capable of immediately absorbing all IFR aircraft in the failed facility. Each ARTCC backs up terminals within its geographical area. When a catastrophic terminal failure occurs, the ARTCC slows the flow rate and provides metering and final spacing commands to arriving aircraft. Whenever an ARTCC or terminal facility fails, there may be a requirement to reorganize the roll call of the data acquisition system that is providing the positional information to both facilities. Whenever a data acquisition system fails, it will be necessary to include the aircraft in the roll call of other data acquisition systems. These comments are general and incomplete. A fully developed bachup plan for the upgraded Third Generation System should be based in part on a plan for the present system.

4.3.6 Availability and Cost

In order to determine whether automation systems of sufficient capability would be available as required and in order to gauge the cost of such systems, a study of the maximum terminal, en route, and central flow control system was performed by the Committee. The study indicates that automation capability available in 1975 is adequate to perform the additional functions described in the preceding sections, assuming twice the traffic forecast for 1995 and a more complex data acquisition system than the one finally recommended.

Computer Sizing Estimates

In order to estimate the computer hardware required for levels of automation beyond NAS/ARTS, a computer sizing group was asked to estimate the instruction rate necessary for a traffic load approximately twice that forecasted for 1995.

Estimates of the computer instruction rates required to perform all systems functions for a traffic load of 100,000 instantaneously airborne aircraft over the continental United States, as well as 8,000 instantaneously airborne aircraft in the maximum terminal area at peak period, are given approximately below.

Enroute Instruction Rate --------- --- 7.5x1@ Inst/Sec.
Terminal Instruction Rate- ________ -_ 9.0x 10" Inst/Sec.
Central Flow Control Instruction Rate- 0.5~108 Inst/Sec.

These estimates were adjusted to account, for a varying instruction mix, the executive control function, and the use of a high level (compiler) programing language. After adjustments had been applied, the maximum computer throughput. rates (in terms of the fastest computer instruction)[2] were determined and their approximate ranges are listed below :

Enroute Instruction Rate------ 45 to 90x10⁸ Inst/sec.
Terminal Instruction Rate------ 55 to 105x10⁸ Inst/sec.
Central Flow Control Instruction
Rate ------- ______________ 25 to 5x10' Inst/sec.

The range is as wide as indicated because of uncertainty in the multipliers to apply for the executive and compiler functions.

A projection of computer technology indicates that reliable processors available for delivery in 1975 will be capable of a maximum instruction rate of 20 X 10^6 instructions per second. Thus, in order to achieve the indicated throughput rates, a multiprocessor system will be required. The multiprocessor configuration will also permit structuring of processor configurations capable of delivering maximum instruction rates of between 20 and lOO+ million instructions per second. Redundant processing elements are accounted for by the executive multiplier.

Storage Requirements

Computer sizing [3] studies also indicated maximum requirements for the data base and operating program storage for twice the 1995 en route, terminal, and national flow control functions. Estimates of both on-line (fast-access time) storage, and mass (slower access-time storage) were made. The approximate summary requirements for these maximum systems are given below :

	En route	*Terminal*	*Central flow control*
Total storage:			
Fast store-- _____	1,500,000	550,000	64,000
Mass store _______	1,350,000	550,000	32,500,000

NOTE.-All estimates are given in 32 data plus 4 parity bit words.

Availability and Hardware Costs

The hardware availability and cost projections were based upon the automation technology projected to exist in 1975. Whereas today's fastest reliable processors have maximum instruction rates between 1 and 4 million instructions per second! the processors of 1975 are projected to have a maximum instruction rate of 20 X 10^6 instructions per second, a gain of 5 in hardware speed.

At the same time, radical changes in computer component structure will take place. These changes will result principally from the higher levels of component integration achieved by semiconductor vendors. The principal result of this higher level of integration will be a decrease in cost of hardware.

The present cost of a logic node, including the loading factors of wiring, packaging, cooling, and power, varies from $3 to $4.50. This cost is projected to drop to $1 per logic node in 1975 (all projections being based on 1969 dollars).

Based upon a projected cost of $1 per logic node in 1975, processor complexities of 30 to 60,000 logic nodes, fast memory cost of 5 cents per bit, mass memory cost of $001 per bit, and buffer (cache) memory costs of $.20 per bit, an estimate of the hardware cost of the maximum automation system required for the 1990 en route, terminal, and central flow control system has been generated. These component hardware costs must be multiplied by a factor of four[4] to eight to obtain typical prices for each of the maximum en route, terminal, and central flow control computer elements :

Terminal-------------------- 6 to 12 million dollars
En route _____ --- _____ ------- 12 to 25 million dollars
Central Flow Control _________ 3 to 6 million dollars

If it is desired to implement functions of this system before 1975, the present WAS en route and ARTS III terminal systems are both capable of multiprocessor augmentation and expansion and appear to be able to handle the traffic loads to at least 1980. At a later point in time, replacement of the current, equipment by equipment reflecting more modern technology will be required at high density facilities.

This computer sizing effort addresses the hardware requirements and costs to achieve higher levels of automation The feasibility of software to achieve the higher levels of automation can only be determined after the recommended development effort.

Reliability Considerations

In any system of air traffic control in which automation is made responsible for control of functions critical to human life, reliability is of paramount importance. Projections of automation/computer reliability indicate that reliability gains of atleast an order of magnitude will be achieved by 1975, largely as a result of improved methods of manufacture of logic and memory components. Thus system reliabilities with mean times to failure of 10,000 hours are possible in the 1975 time frame. However, improvement in component reliability will not be adequate to achieve the levels of per-

[2] It has been assumed that the average instruction is 1.95 times the fastest instruction.
[3] Appendix D.
[4] This factor includes labor, overhead, etc.

formance required to meet minimum safety requirements for the air traffic control system. In order to achieve the required levels of safety, a system will be required which is tolerant of component failure and can recover and redistribute workloads to other components when a failure condition does, in fact, occur. Such systems already are under development and permit fail safe and fail soft modes, i.e., modes in which the failing component is isolated and the remaining system elements take over the function of the failed component, or alternately, transfer to essential tasks, leaving noncritical tasks undone.

Such systems need considerable additional development before they can be considered dependable enough to be self-sufficient without complete manual backup. Work in this area of development is critical, for as air traffic continues to increase, a workload will soon be reached wherein a complete manual backup for the automation system will not be physically possible. Certification of -automation equipment must include not only a guarantee of the reliability and upgraded mode capability of the hardware system, but also must include a method of complete checkout and certification of the software (programming) system.

Software Complexity, Cost and Lead ***Time***

The estimate for the software includes labor, overhead, and profit, but has no inflation factor. This estimate considers the Executive Monitor Program separate from the rest of the operational programs because of the difference in complexity. The Executive Monitor Program will be a highly sophisticated and complex program that performs the required task scheduling based on the system's resources. The requirements of a real-time multiprogram system dictate a sound executive control structure to handle efficiently all of the data processing functions, dynamic storage allocations, the control of input/output data as well as the fail safe/fail soft considerations. The Monitor provides for the detection of hardware errors in both system modules as well as in the peripheral equipment., and it provides for the necessary reconfiguration tasks. Dynamic reallocation via. relative addressing is not only used to efficiently utilize the memory resources but also for reconfiguration.

The fail safe/fail soft considerations of the Executive Monitor Program constitute the predominant portion of this program. It includes critical operational data collection, error detection, data processing, module partitioning control, status reporting, dynamic reconfiguration reloading, resource reassignment, critical data reconstruction, and the restart of the operational program.

The Enroute Executive Monitor Program is estimated to cost $28 per instruction and requires a 2- to 3-year lead time. This amounts to a total of $2,800,000.

The Terminal Executive Monitor Program is estimated at $28 per instruction and requires a 2- to 3-year lead time. This amounts to $2,100,000.

The Enroute Operational Programs adapted for all centers that consist of the collision avoidance, data acquisition, command and control and additional enroute functions, are estimated to require a 5-yearlead time. The total cost for the 20 centers that cover the continental United States then is ***$34,500,000.***

The Terminal Operational Programs, adapted for all terminals, are estimated to require 4 to 5 years. The total cost, for the 36 high density terminals is estimated to be $39,000,000. The National Flow Control Operational Program is estimated to cost $1,200,000 and requires a 2- to 3-year lead time.

In summary, the programming cost (including program design, development and check out) for the Sntional Flow Control Systems is estimated to be $1,200,000; the Enroute Center System for the entire country is estimated to cost $37,300,000; the Terminal System for the ***36*** high density airports will cost an estimated $41,100,000.

4.4 NAVIGATION AND LANDING AIDS

The upgraded Third-Generation System that can handle the traffic forecasted through 1995 can be served by the current VORTAC system with compatible modifications for the required navigation services, however, it must have the recommended microwave ILS as a replacement for the current landing aid. Moreover, area navigation capability in the fleet must be widely implemented for access to high-capacity, dense airports.

It was shown earlier that area navigation routes with 2-mile separation are needed to feed high-capacity airports of the future. This route separation is required from the limits of coverage of the microwave ILS to approximately 25 miles from the airport. More than 25 miles from the airport, 4-mile route spacing seems adequate; beyond ***40*** miles from the airport, the current 8-mile separation seems sufficient from the projected traffic density.

The added performance needed for the future can be achieved mainlv through improved standards for airborne equipment. VOR ground equipment improvement, selectilse precision VOR implementation, expansion of facilities through introduction of 50-kHz channel spacing, and judicious planning of area navigation routes. These changes can satisfy anticipated route width decreases as well as adapt to area navigation concepts without undue strain with respect to airborne equipment compatibility. Furthermore, it is expected that STOL operations, both terminal and en route, can be achieved using VOR-DME with coverage down to 1000 feet. Some relocation and a number of new sites may be needed to accommodate area navigation routes for intercity and for the new STOL terminals.

Of course, VOR is insensitive to the number of aircraft. This is not true of DME. There are not enough DME channels available to increase the number of DME facilities to provide adequate capacity for 1995. However. there are techniques available to increase the capacity of individual DME stations so that the total DME capacity can be made adequate for the traffic of 1995.

In the case of the landing aid, the ILS presents a serious constraint to added capacity through its single-course-line character. its overflight interference problem that forestalls reduced longitudinal spacing, and its general sensitivity to siting, particularly at large terminals where increasingly large structures are expected. Sew technology is available, in advanced development status, in the form of microwave scanning beam landing aids that provide features needed at the high-density terminals.

The ILS is not suitable for V/STOL ports because of its inherent. size and its sensitivity to surroundings. A microwave scanning-beam system seems most appropriate for this application and should be designed for compatibility with the V/STOL facilities.

Final approach and landing systems must meet several requirements in order to achieve the levels of airport capacity described in Section 3.2. Primary among these are :

1. Wider proportional deviation in azimuth to achieve multiple curved precision tracks to asymptotic intercepts of the runway course line. This is necessary to achieve optimum sequencing of mixed aircraft types closer runway spacing, and noise abatement approach routings.

2. Distance measurement accuracy to achieve a delivery precision of .5 seconds (1 sigma) for arrivals at the runway threshold.

3. Over-runway and departure guidance for missed approach and noiso abatement departure routings.

4. Overflight interference removal so that reduced longitudinal spacing between arrivals and departures can be achieved.

4.4.1 Improving the Navigation System

Relationship Between Navigation Accuracy and Route Width

The system of routes used in the United States has width or route protection based on a VOR system accuracy of t4.5 degrees on a 95-percent probability basis. The ±4.5 degrees for VOR justifies the application of ±4 nautical mile route widths out to a distance of 51 nautical miles from the facility and a widening of route protection on the ±4.5 degree basis beyond 51 nautical miles. In addition, the airway system permits reduced airway widths to x 3 nautical miles under certain circumstances out to 34 nautical miles. Helicopter operations hare been authorized, based on VOR, with route widths of ±2 to 25 nautical miles.

These route widths are computed by root-sum-square (rss) of the 2-sigma values of the major system component errors. The component errors usually applied are ground system error, airborne system error, and flight technical or pilotnge error. The ±4.5 degree criterion is composed of the. following representative elements:

1. Ground—±1.9 degrees
2. Pilotage—± 2.5 degrees
3. Airborne—±3.2 degrees

The DME error is considered generally to be ±0.5 nautical mile or ±3 percent, whichever is greater. In both the DME and VOR cases, the more modern airborne equipments exceed the foregoing stated performance, with the DME being closer to +2 nautical mile, and the VOR somewhat less than ±2.7 degrees.

In the computation for area navigation route widths, the rss expression must include the 2-sigma error value for the area navigation airborne equipment. This element is based on performance of input/output signal conversion: computing process, displays, course definition entry devices, and charts. where. used. Within the present state of the-art. airborne area navigation equipment are available. yielding error contributions ranging from ±2.5 nautical miles in their worst operational situation to approximately ±0.2 nautical mile under best operational situations. Since VOR/DME is an angular system (rho/theta), quite high total system accuracy can be achieved in the terminal area (or near the facility) where the area navigation display scale factors can be optimized, and the other major error sources also tend to be smaller.

Methods for Improved VOR-DME and Navigation

There are a number of procedures and equipment designs that can be adoptecl to achieve higher levels of navigation performance and, accordingly, closer route spacings. All of these methods are now available, either in the form of procedural changes or in the form of existing hardware. The existing hardware has been proven experimentally and in some cases is higher-performance production equipment nom in limited use.

The following list broadly describes the alternatives that may be used separately or together to achieve the desired levels of accuracy :

1. Take advantage of higher-performance ground facilities such as precision VOR and Doppler VOR, together with optimized location, as appropriate.
2. Limit range of use to relatively short distances, especially in terminal areas.
3. Require that airborne equipment (presently available) be designed for higher level of accuracy.
4. Use more sophisticated signal processing (or smoothing) together with constant-deviation displays that may have selectable scale factors and, perhaps, integral heading indications.
5. Require auto-couplecl use for the higher levels of performance.

As an example of the accuracies achievable with good, but state-of-the-art, equipment it is believed that a 2-nautical mile route width is obtainable using current ground rules for the rss-error budget computation :

Ground VOR rndinted signnl error	± 1.1 degrees
Airborne VOR equipment error	-t 1.0 degrees
VOR aggregate error	± 1.48 degrees
Area nnrigntion equipment error	i-0.9 n.m.
Pilotage element [1]	±0.5 n.m.
Route width nt 25 n.m.	± 0.03 n.m.

[1] A modern flight director or autopilot is required to accomplish this.

The foregoing case assumes VOR to be the predominant factor in the error budget, rather than DME For locations of the VORTAC with respect to the route such that DME is the major factor in the error budget, the result would be improved, particularly if the higher quality of available production airborne equipment were used. Additionally, precision DME feasibility has been demonstrated in the role of an approach and landing aid, which could be extrapolated to greater coverage if found warranted. Precision DME is compatible with current standard equipment and requires a modified airborne equipment to extract precision performance with a 1-order-of-magnitude accuracy improvement.

Other En Route and Terminal Transition Navigation Aids

Although it is believed that the VOR-DME system can meet foreseeable requirements, there are other aids whose roles in short-range navigation are now under review. Inertial navigation is being adopted for its long-range navigation application, particularly over ocean routes. Its existence in some cockpits warrants attention to its possible application during domestic operations. Since it is expensive, it is not recommended as the prime navigational aid and is not likely to be required to enter any airspace: it should be adapted to work with VOR-DME. The options for its use in this respect, are variable. It may bc independent it. may be used complementary to VOR-DME, or it may be a cross-reference to VOR-DME. Its inherent "area navigation" features, especially in its computer mechanization. tend toward at least some commonality with VOR-DJIE area navigation computation and display.

Loran C/D and Decca are candidate systems that offer high accuracy and non-line-of-sight characteristics although they are somewhat susceptible to spherics. Consideration for their use is tempered by the current widespread implementation of VOR/DME, its potential for improvement, the high airborne equipment costs for Loran C/D and Decca (particularly for general aviation), and the lack of a clear requirement for a non-line-of-sight navigation aid.

Vertical Navigation

Accurate altitude measurement is necessary to assure vertical separation between aircraft and for terrain avoidance. Although there have been a number of technologies investigated in the past.

barometric measurement has continued to be the standard, based on economic and technical considerations. Vertical navigation' in final approach to landing, of course, uses ILS glide slope and in some cases radio altimetry. Even in these cases, barometric altitude is used for checkpoints and decision heights.

A more recent application of barometric altimetry has been its combination with DME information to compute a let-down path based on height and slant-range inputs. This type of "let-down computer" is envisaged as a possible tool for reduced noise on approach by computing a steeper glide prior to intercept of the ILS glide slope. This places the aircraft higher above populated areas than achievable by current procedures. This type of approach has proven feasible in test aircraft. Also, the "let-down computer?' may have application in climb and descent corridors to high-capacity airports.

During level flight, vertical separation standards require 1000-foot separation up to 29,000 feet MSL with 2000-foot separations above 29,000 feet. For mixed IFR and VFR traffic below 29,000 feet? WI-foot separations are observed between VFR and IFR levels.

It does not appear likely that a general reduction in vertical separation distance will become feasible during the period under consideration. Based on measured data, there is a possibility that by using high-quality airborne systems, in airspace above FL 290, separations may be reduced below the present 2000-foot standard.

The following factors are the major sources of altitude error:

1. Instrument error-translation to display or digital code caused by mechanical and/or electromechanical imperfections in the pressure transducer

2. Installation error-measurement error of ambient barometric pressure and transmission to instrument, including static pressure system calibration tolerance

3. Flight technical error-random deviation from intended altitude incurred by manual or autopilot control and influenced by turbulence

Table 36 outlines current understanding of altimeter performance and extrapolations based on the assumptions described below the table. This table does not reflect the aircraft vertical dimension factor, nor does it include the effect of turbulent air.

TABLE 36.-*Altitude error (feet-3 sigma).*

Altitude	Instrument	Installation	Flight technical [5]	Total RMS error
Possible [1] 0	20	75	250	260
40,000	80	115	250	285
Present [2] 0	20	[4] 90	250	265
40,000	230	[4] 250	250	420
Present [3] 0	20	[4] 250	250	355
40,000	230	[4] 750	250	860

[1] Based on use of best currently available equipment, calibration tech niques, and use of autopilot.
[2] Based on use of minimum required IF R altimeter, correction of static system to aircraft manufacturer data, and use of autopilot.
[3] Same as (note 2) except no correction of static system error.
[4] Includes additional 25 feet for repeatability.
[5] Assumed independent of altitude.

4.4.2 Expansion Potential of VOR-DME

There are presently 973 VOR's, 377 ILS's, and 720 TACAN/DME's in operation within the continental United States. These include all military, civil, government, and nonfederal facilities. Many facilities are Canada, Mexico, and the Bahama Islands and must be considered in the frequency allocation process.

At present, VOR facilities are assigned frequencies on the even tenths of a megahertz from 106 to 112 MHz, and on every tenth of a megahertz from 112.1 to 117.9 MHz. The ILS localizer is assigned odd tenths of a megahertz from 108.1 to 111.9 MHz and is paired with glide-slope facilities, which are at 300-kHz increments from 329.3 to 335.0 MHz. The TACAN/DME is assigned on l-MHz increments from 962 to 1213 MHz (X channels only) and is paired with VOR/ILS in common system" channels. There are 79 assignable VOR frequencies, 19 assignable ILS frequencies, and 98 assignable TACAN/DME channels in the "common system" channels.

Present Channel Congestion

New VOR, ILS, and DME frequency assignments have become very difficult to obtain within the Boston-Sorfolk-Chicago triangle and within 200 miles of both Los Angeles and San Francisco.

In many cases, in order to "squeeze in" one more facility or change a VOR class from "L" to "H," an extraordinary number of shifts or a "chain reaction" is entailed in adjacent facilities.

Generally, the requirement for additional VOR's is not expected to be very large. Present plans call for 23 additional facilities. Area navigntion will not necessarilv cause a significant additional increase in facilities; with judicious placement of stations, in certain areas, quite the opposite is possible. However, in the V/STOL situation, if high-volume operations occur intracity and intercity, there may be a need for additional facilities, especially to satisfy terminal and low-altitude performance requirements.

The number of ILS's is expected to at least triple during the next decade. This will become a severe problem since, using present ground rules, 41 contiguous channels would be required. If all directional localizer arrays are used (V-ring), this number becomes 31.

This situation requires some special procedures which must be more thoroughly analyzed prior to decision. However, typical alternatives are conversion of 8-loop localizers to V-ring, common frequency assignments to ILS localizers on the same airport, and/or assignment of additional channels, if 50-kHz channel spacing in VOR permits.

Accommodation of all known planned facilities mill saturate ILS/DME channels and near-saturate VOR-DME frequencies. There mill be little or no room for post-1975 VOR-ILS-DME growth 'unless some form of channel expansion becomes available. This expansion can be provided by 50-kHz channel spacing in VOR together with some form of ILS control--either directivity or shared-use, or both.

DME Traffic Capacity

All of the approximately 600 TACAN and DME ground stations operated by the FAA now have a maximum traffic-handling capacity of approximately 100 aircraft. This limitation is imposed by the ratings of maximum duty cycle on the transmitter tubes at maximum peak power levels. Protection circuits are included in all present ground stations to reduce the receiver gain as soon as the 100 maximum interrogators are exceeded.

Approximately 315 of the present ground stations are Model RTN-2 TACAN equipments that were designed for 23.5 km peak power output but are being operated presently at a maximum of 10-kw peak power because of the probability of co-channel interference. If the present peak power limitation is maintained, which seems reasonable since no co-channel problems have appeared, these transmitters could be operated very easily at twice the present average power, while maintaining the same peak power, thus allowing a concomitant increase in duty cycle and traffic-handling capacity at twice the present value. Modification of the traffic overload protection circuits and readjustment of the equipment would be all that would be required.

The remaining ground TACAN equipments operated by the FAA would require a redesigned transmitter, modular, and high-voltage power supply to operate at the higher average powers associated with an increase in duty cycle. However, a limitation from another source would begin to be a factor at about 200 to 250 aircraft per ground station. This arises from the fact that the majority of the presently used interrogators utilize near the maximum interrogation rate (PRF) of 30 per second average. Some of them will not track distance below the 50-percent reply signal specified although many units will operate with as low as a 25-percent reply rate. This is advantageous since the receiver in the ground station must use additional time for multipath or echo suppression after decoding an interrogation and must also be suppressed during the transmission of the reply.

Fortunately, this limitation can be overcome by reducing the interrogation rate of the interrogators and/or improving the ability of the interrogator to acquire and track a signal with a lower percentage of replies. The newest type of interrogators use all-digital techniques and search and track with about one-half the rate of previous designs. This raises the capacity of a single station to as high as 500 aircraft.

Furthermore, by a more precise control of circuit parameters and refinement of interrogator performance tolerances, a further doubling of the traffic-handling capacity of the stations could be effected since the interrogator can operate with less than a 50-percent, reply efficiency. This increases the capacity to more than 800 aircraft per station. It is concluded, therefore, that the distance-measuring traffic capacity is not a serious constraint to the VOR-DME system.

4.43 Approach and Landing Aids

Section 3.2 described the requirements for both a landing aid to provide high-capacity service and many of the shortcomings of the current ILS. Technology is now available to replace ILS as operational and economic conditions dictate. The economic and operational factors indicating replacement at high density terminals are quite clear. Not only is capacity a factor in this case, but also there is a consensus that the replacement can serve as a redundant source to ILS for Category III operations to bolster reliability and assure safety, especially during the early phases of this kind of operation. Implementation at

V/STOL ports of a new landing aid is also clearly warranted for reasons previously mentioned relating to siting effects and equipment size considerations.

Microwave Landing Systems

During the past decade, manv candidate replacement landing aids hare been investigated in development programs by military and civil agencies, both nationally and internationally. There is a growing consensus that the scanning-beam concept is the primary contender not only for civil fixed-wing and V/STOL use, but also for military strategic and tactical use. This concept has particular attraction in its adaptability to most operational missions in various basic hardware forms. It can be made to provide coverage, performance, and capacity demands for the high-clensity terminal. It has been shown to perform in a modest form for smaller general aviation airports, and it appears capable of adapting to tactical form factors for portability and rapid deployment for military purposes.

There appears to be no reason why such a landing aid cannot be made in these various forms and still retain compatible signal format for interchangeable civil and military use. This is the goal of RTCA Committee SC-117, which is constituted of various government and civil interests to develop a common signal format for a new national standard landing aid.

Scanning-Beam Microwave Landing Systems

The principle involved in scanning-beam landing guidance uses "fan-shaped" beams scanning rapidly in the azimuth and elevation planes in a manner similar to GCA or PAR does today. These beams are angle-coded so that as they scan past the airborne receiver antenna, azimuth and elevation information may be decoded. Optionally, a distance measuring function is interspersed in the timing cycle as the beam passes an aircraft. This is done by interrogator-transponder, much as current the DME performs, but with a higher precision of measurement. By time-multiplexing, the azimuth, elevation. and distance measurements use a single radio frequency per ground station. which provides three-dimensional space position anywhere within the scan coverage.

There are a few clerelopmental versions of scanning-beam landing aids non- operating. Although they are all based on the general principles described earlier, there are various basic differences in mechanization. Frequency spectrum considerations dictate that this type of aid must fall within either the Ku band or C band in order to obtain sufficient bandwidth for channelling.

The most extensively tested system to date is a Ku-band equipment. This equipment was designed to demonstrate feasibility and has achieved that goal although several features that are necessary operationally were excluded. For example. coverage is limited both in azimuth and elevation, and no coverage is provided over the runway or in the departure zone.

The following conclusions are derived from the test results :

1. accuracy : (1 sigma)
   elevation ± 0.03 degree
   azimuth ± 0.05 degree
   distance $\pm$ 100 feet
2. Taxiing, landing, and departing aircraft caused no significant interference with the signal being received by an approaching aircraft.
3. Elevation guidance accuracy was maintained down to 0.4 degree.
4. Collocation with KS produced no mutual interference problems.

Other scanning-beam equipment are being developed to operate at C band. Some use step-scan methods. some use analog beam-splitting, and others digital. Generally, the differences are not major with respect to basic performance. Major remaining decisions relate primarily to choice of frequency band and definition of common signal format.

The scanning-beam concept achieves relative insensitiritv to multipath propagation problems primarily because of its highly directional property. Accordingly. the frequency choice between Ku and C bands is influenced by the following factors now under consideration.

1. Antenna size
2. Propagation attenuation during rain and snow
3. Radio-frequency component costs and reliability

The Ku band, of course, offers the possibility of smaller antenna apertures, and C bnncl is better in propagation and rf component aspects. The selection is not clear since, (1) electronic scan antennas may overcome antenna size problems for C band. (2) propagation difficulty at Ku band is not absolutely constraining, and (3) component cost for Ku bnncl may become competitive with C band at some future time.

5. RECOMMENDED DEVELOPMENT PROGRAM

The FAA's problem is similar to that of a public utility-a steady, fairly predictable growth in demand requiring a continuing growth in services with an accompanying growth in technology. An appropriate response to this situation involves both long range planning and a continuing R&D program to prepare for future needs. The Committee has been hampered in its efforts by a lack of an adequate R&D and data base on which to predicate its recommendations. This is related to a long history of austere R&D budgets for air traffic control. The Committee is convinced that a policy of low RCD expenditures is not economical, but is, in the long run, very expensive, especially in an area of high and rapidly advancing technology such as air traffic control. In addition to the major R&D investment needed in the near future to cope with the present problem, the Committee recommends a general policy of increased R&D effort for air traffic control. However, to be effective, this effort must be closely coupled to overall system planning and system engineering. System engineering! in turn, requires an intimate knowledge of current operating problems.

The research and development recommendations are categorized into three major groups :

1. Increase airport capacity to satisfy the demand in the 1975 to 1980 period and beyond.
2. Provide en route and terminal airspace capacity adequate for the traffic of the 1980's.
3. Determine the ingredients of a Fourth Generation ATC System for the post 1990 period.

PROGRAM 1 OBJECTIVE: INCREASE AIRPORT CAPACITY

1. Perform major urban airport system studies dealing with capacity increase and noise reduction possible through ('1) dual lane runways, (2) close spaced parallel runways, (3) curved approaches based on scanning beam micron-are ILS, (4) two step glide slope, (5) power cutback during climb. (6) retrofit of the four-engine jet. fleet with quiet nacelles, and (7) addition of terminal automation capability of the ARTS III program, such as commnncl control sequencing and data link formatting.

Estimated Duration : 2 years.
Estimatecl Cost; $4 million.

2. Develop. test, and evaluate a wide-angle scanning beam microwave ILS for the high density terminal as well as a simplified microwave ILS for the low density or general aviation airport. Develop the airborne course computers to operate with the scanning beam microwave ILS so as to perform system tests. Evaluate feasibility of transmitting aircraft cross track position to the ground.

Estimated Duration; 3 years.
Estimntecl Cost; $10 million.

3. Conduct flight. tests to (1) verify the safety of closely spaced parallel and curl-ccl approaches utilizing guidance derived from the scanning beam microwave ILS, and (2) prove the safety of nominal time separation and reduced longitudinal separations utilizing the recommended data acquisition system as a monitor.

Estimated Duration : 3 years.
Estimatecl Cost ; $8 million.

4. Develop procedures for evaluating the wake turbulence hazard and measuring vortex locations and intensity and for providing this information to ATC. Test the vortex suction technique for clearing runways of wake turbulence. Conduct exploratory work including vortex decay by blowing.

Estimated Duration ; 3 years.
Estimated Cost ; $5 million.

5. Develop systems for detection and control of aircraft, and vehicles on the airport surface.

Estimated Duration; 3 years.
Estimated Cost.; $10 million.

PROGRAM 2 OBJECTIVE : INCREASE THE ES ROUTE ASD TERMINAL AIRSPACE CAPACITY OF THE THIRD GENERATION AIR TRAFFIC CONTROL SYSTEM TO ACCOMMODATE TRAFFIC UP TO THE 1980's

1. Conduct a system integration study of the upgraded Third Generation ATC System.

a. Integrate the upgraded ATCRBS, including its data link and computation facilities with the upgraded NXS and ARTS systems.

b. Develop an upgraded ATCRBS implementation plan with and without a frequency change from 1030-to-1090 MHz to 1560-to-1575 MHz. Study the feasibility of operating components of the current XTCRBS at 1560 to 1575 MHz, as well as incorporating a data link.

c. Define the services that. should be provided in Mixed Airspace when aircraft are equipped with the upgraded ATCRBS. Where are "VFR Highways" appropriate, what is required to enter and navigate them, where is IPC service appropriate, how does the mix of upgraded ATCRBS and standard ATCRBS beacon affect the quality of IPC? Develop and evaluate IPC conflict detection and resolution software for various traffic densities and distribution. Develop and evaluate "VFR Highway*? concepts and the required software for various traffic densities and distribution.

d. Define the services that should be provided in Positive Controlled Airspace when the ATC data-link beacons are part of the upgraded ATCRBS. How are clearances requested, providecl, and verified? How are ATC commands in the en route and terminal airspace provided and acknowledged? How are ATC warnings and missed approach directives provided? How do these services reflect in the system design!

e. Develop a comprehensive reliability plan for the Third Generation System, including the ATCRBS, ARTS, NAS towers, landing and navigation aids, radar surveillance, and communication systems. The recovery modes from failure of any of the components of the system or its interconnections should be carefully developed. Simulation of these recovery modes should be conducted with great care, and personnel should be rehearsed in their execution. A comprehensive plan for increasing the inherent. reliability, for providing sophisticated preventive maintenance, and for improving the reliability of the present system should result from this study. Another result should be the specification of the inherent reliability, redundancy, and recovery modes of the upgraded Third Generation System. This should be verified by real-time simulations. Specifications should be prepared for all parts of the system as a result of these tests. If these tests indicate an independent, air derived backup mode is required, specifications should be prepared and its integration with the ground environment should be specified.

Estimated Duration ; 3 years.

Estimated Cost ; $25 million.

2. Modify the ATCRBS to provide increased surveillance accuracy and to achieve better reliability by adding a discrete address mode data-link function. The ground based interrogator in a high density terminal should be a phased array with substantial horizontal and vertical aperture. The interrogator for the small terminal should be developed. The sophisticated airborne component should be capable of (1) 100 to 200 foot range accuracy, and (2) initiation, receipt, and verification of flight clearances. The general aviation airborne component should be capable of verification and acknowledgment of IPC commands and initiation, receipt, and verification of "VFR Highway" information should the system study indicate this mode to be desirable. Develop a reliable, low cost altitude encoder.

Estimated Duration; 3 years, but requires priority.

Estimated Cost ; $40 million.

3. Develop the full center automation (NAS) program, including conflict detection and resolution, flow control sequencing and metering, and those portions of IPC and ATC data link assigned to the centers as a result of 2.1. Provide experimental facilities for simulation and live testing.

Estimated Duration ; 3 years.

Estimated Cost; $30 million.

4. Develop the full ARTS program, including command control sequencing, threat evaluation of deviation from parallel courses, intruder detection and resolution, and those IPC and ATC data link functions assigned to ARTS as a result of 2.1. Provide experimental facilities for simulation and live testing.

Estimated Duration; 3 years.

Estimated Cost; $30 million.

5. Institute an adequate research program in the techniques and data collection area to assure a more complete data base for future development in various areas. This would include research into multipath, coding, and synchronous techniques? improvement of communication system reliability. and review of satellite system technology for over-ocean surveillance and communication.

Estimated Duration; 3 years.

Estimated Cost: $15 million.

PROGRAM 3 OBJECTIVE: TEST THE FEASIBILITY OF MAJOR INNOVATIONS IN THE AIR TRAFFIC CONTROL SYSTEM THAT MIGHT BE KEY INGREDIENTS OF A FOURTH GENERATION SYSTEM

1. Perform studies on automating the ATC system. Is it possible to achieve the reliability in software and hardware necessary when the ATC decision process is mechanized? What is the man-machine relationship as automation proceeds well beyond the NAS and ARTS level? Will an automation approach based on fundamental air traffic flow, capacity, and safety consideration be different and better than incrementally increasing the automation capability of NAS/ARTS ?

Estimated Duration ; 5 years.

Estimated Cost; $15 million.

2. Conduct system studies on the use of a cluster of synchronous satellites as a base for data acquisition, navigation, communication system for aircraft in the continental United States. Study a signal processing system adequate to service all instantaneous airborne aircraft in the post 1990 period. Study the vulnerability of a satellite system, including its ground complex. These problems and others should be part of this study to determine the feasibility, economics, and desirability of a system employing satellites as a data base for an air traffic system in the period beyond 1990.

Estimated Duration ; 3 years,

Estimated Cost; $10 million.

The recommended research and development effort is not exhaustive, it treats only items of highest priority. Some of the programs are included in FAA plans or are based on previous FAA efforts. Some are not. All are organized to provide the basis for achieving a given system objective (in safety, efficiency, or capacity) by a certain time. The recommended funding levels are estimated to complete the R&D in advance of the predicted requirements. Table 37 shows the recommended developmental program contract costs.

TABLE *37.-Recommended development program contract costs.*

program	Cost (Millions)	Duration (Years)
1. Increase Airport Capacity:		
1.1 Urban Airport Retrofit Studies	$4.0	2
1.2 Microwave ILS Development	10.0	3
1.3 Flight Tests of Reduced Separation	8.0	3
1.4 Wake Turbulence Studies	5.0	3
1.5 Airport Surface Traffic Control	10.0	3
Total	37.0	
2. Increase Airspace Capacity:		
2.1 System Integration Study	25.0	3
2.2 Develop Discrete Address ATCRBS	40.0	3
2.3 NAS Automation Extension	30.0	3
2.4 ARTS Automation Extension	30.0	3
2.5 Technique Developments	15.0	3
Total	140.0	
3. Fourth Generation System:		
3.1 Studies Toward Higher Automation	15.0	5
3.2 Satellite System Studies	10.0	3
Total	25.0	
Subtotal	202.0	

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APPENDIX A-Committee Members

Ben Alexander (Chairman)
Chairman of the Board and Technical Director
General Research Corporation

Lawrence A. Goldmuntz (Executive Secretary)
Office of the dssistant Secretary for Research and Teclmology
Department of Transportation

Thomas S. Amlie
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Deputy Assistant Secretary for Research and Technology
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Case Western Reserve University

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John R. Meyer
President, National Bureau of Economic Research

Courtland D. Perkins
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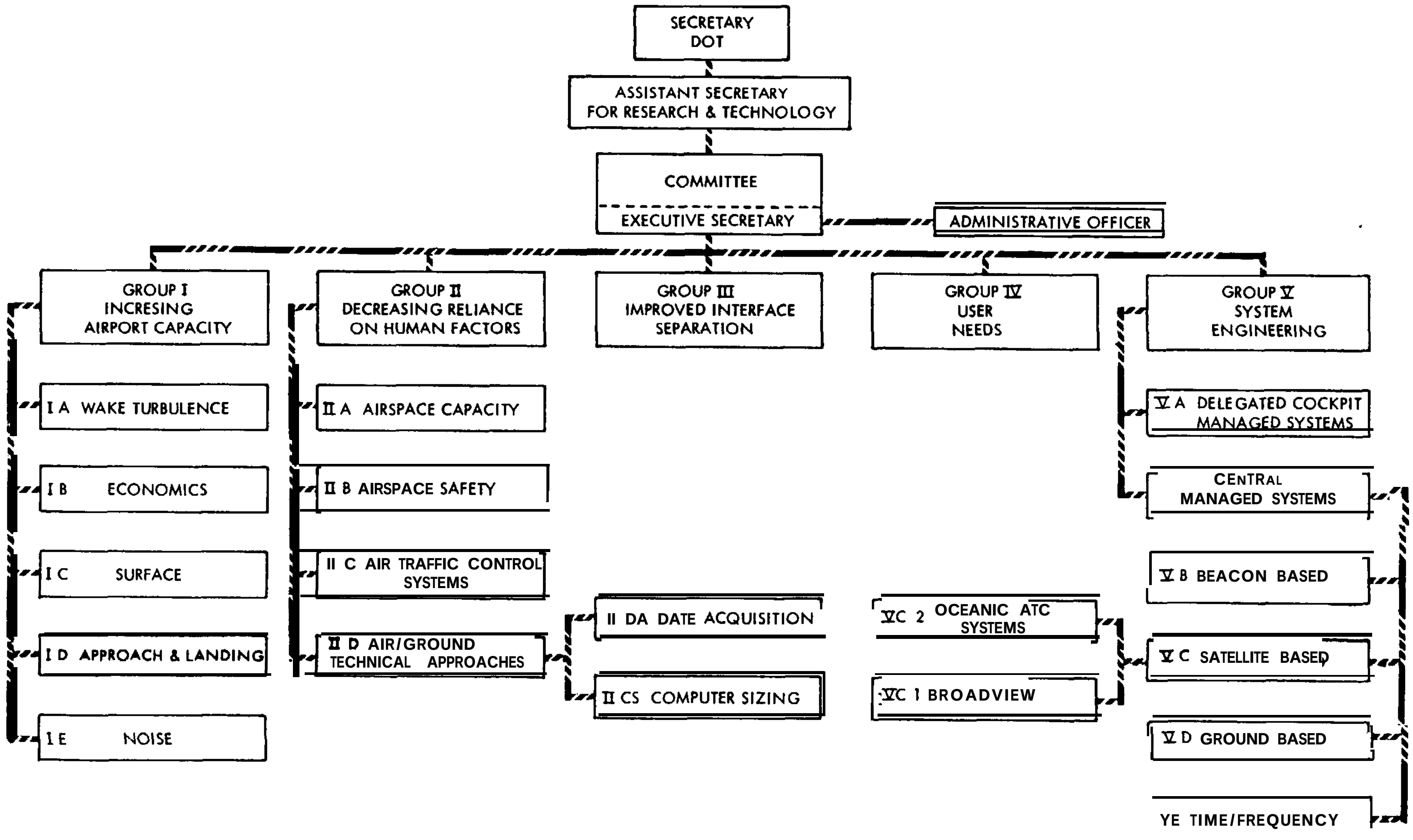
Jack P. Ruina
Vice President for Special Laboratories
Massachusetts Institute of Technology

Gen. J. Francis Taylor
President, Aeronautical Radio, Inc.

DOT AIR TRAFFIC CONTROL ADVISORY COMMITTEE ORGANIZATION CHART



APPENDIX I

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GLOSSARY

Air Carrier-An aircraft certified by the FAA for the purpose of carrying persons or goods for hire on an established airway. The term also applies to an organization operating an air carrier.

Air Derived-Information generated on an aircraft.

airport Surveillancc Radar (ASR)--FAA short-range radnr for terminal air traffic control.

Air Traflc-Aircraft operating in the air or on an airport surface, exclusive of loading ramps and parking areas.

Air Traffic Control (ATC)-A service that promotes the safe, orderly, and expeditious flow of air traffic, including airport, approach. and en route air traffic control.

· ***Air*** Traffic Controller-A duly authorized individual involved in providing ATC.

Air Traffic Control System--All components. human and otherwise, of a system providing ATC service.

Aperture Diametcr- The diameter of a radar main beam at its point of origin. Because of the properties of electromagnetic radiation, the angle of spread of a projected beam is related in an inverse manner to the size of the aperture.

Approack Sequence-The order in which aircraft are positioned while awaiting approach clearance or while on approach.

Automatic Overload Control (AOC)-Transponder circuits thnt limit the reply rate to a preset level to control that system performance.

Back Lobc-The lobe of a radar signal that extends in the opposite direction from the main lobe. The black lobe is usually stronger than the side lobe.

Beacon Antenna--An antenna system that radiates radio or radar energy in such a way as to act as a beacon for navigation purposes. See ***radio beacon*** and ***radar beacon.***

Beam Sharpening--An effective reduction in the width of the main beam of an interrogator due to the use of side lobe suppression.

Bracket Decoding-A type of decoding that provides a single-pulse display whenever a pair of bracket pulses are received regardless of the information pulses that lie between the bracket pulses. When this method of decoding is used, all aircraft using Mark X SIF and ATCRBS transponders in the coverage area will be displaying. See ***bracket pulses, Mark X SIF. ATCRBS.*** and ***transponder.***

Bracket Pulses-The first and last pulses of a transponder ***reply*** group thnt are present in all replies. When transmitted without the normal information pulses. the bracket pulses are designated Code O-O-0-0.

Blunder-Occurrence where. as a result of equipment malfunction or pilot error, an aircraft has exceeded safe tolerance from cleared route.

Boresight- Center of the main beam of a radar signal.

Category I Weather-Weather allowing a forward visibility of 1/2 mile. Under Category I, the pilot should be able to see the runway from an altitude not in excess of 200 feet.

Category II Weather- Weather allowing a forward visibility of 1/4 mile. The pilot should be able to see the runway from an altitude not in excess of 100 feet.

Category III Weather- -Runway efiectively not visible from ***any*** altitude and all landing decisions are left to the Pilot. ***Category*** III breaks down into three subcategories.

IIIA Forward visibility is 700 feet, n distance sufficient for a landing abort.

IIIB. Forward vislbility is 150 feet, a distnnce sufUcient to permit taxiing.

IIIC. Zero forward visibility.

Gell-Computer memory section wherein radnr return or transponder response Information is stored and periodically updated-usually after each sweep or interroga***tion.*** Sometimes called bin.

Code Garbling-False code information or cancellation of a desired code which occurs when a reply from a second (spurious) transponder Is found or received at a position in the pulse train reply from the desired transponder.

Coder-A portion of the beacon, transponder or interrogation equipment that ***forms*** the desired pulse train for transmission; the beacon and transponder coder form the proper reply code trains and the interrogation coder forms the desired interrogation code train or mode.

Collision ***Avoidance*** System ***(CAS)-A*** device installed on aircraft for the purpose of:

(a) Detecting the presence of other aircraft.

(b) Automatically assessing the potential collision hazard represented by other alrcraft.

(c) Providing advance wanting to the pilot if a threat is predicted by the equipment.

(d) Providing appropriate command signals indicating the proper evasive maneuver.

The CAS device performs its function continuously and automatically in all types of weather conditions without requiring visnal assessment of collision risk by the pilot. Collision avoidance replaces see-and-be-seen protection by more efficient means of protection and provides more functions than does PWI: it senses the presence of an intruder, evaluates the degree of danger, and commands a ***specific*** climb or dive avoidance maneuver. In common with a stationkeepr, it will work in both IFR and VFR weather, while PWI effectiveness is often limited to VFR.

Committee As referred to in this report, the Committee is the Department of Transportation Air Traffic Control Advisory Committee.

Constellation - A group of three to fire orbiting satellites to be used to augment ATC in the post-1975 period.

Conrtrolled Aircraft~aircrnft that are participating and receiving traffic separation service from the **ATC system.**

Controlled Airspace-Same as Mixed Airspace. It starts in general, at some altitude above the ground and extends up to Positive Control Airspace. In terminal area control zones, it extends to the ground.

Controlled ***Visual Rulca*** (CVR)-Visual flights in which avoidance of collision with all other aircraft is assured by the ATC system. To enable the ATC system to carry this out, CVR flight is restricted to Positive Control Airspace.

Count-down-The rate of beacon interrogations compared with that of parent radar pulses; this term is also used to compare the number of replies transmitted by a transponder with the total number of interrogation pulses received.

Coursc-The intended direction of flight in the horizontal plane.

Cross ***Track*** Velocity-Velocity of an aircraft normal to the intended flight path.

Data Link-Any communication channel or circuit used to transmit data from a sensor to a computer, a readout device, or a storage device.

Dead Reckoning-A method of determination the position of an nircrnft on the basis of indicated airspeed, compass heading, and the beat possible estimnte of wind velocity. Dend reckoning 1s a lnst resort when all other nnvjgntion methods fnil.

Decca Navigation--A form of hyperbolic navigation in which the master station normally operates with two slave stations. This system is characterized by the use of continuous-ware signnls. ***See Loran.***

Decoder-A device or subsystem in the ground equipment that transforms the beacon or transponder reply code information ***into*** a form suitable for display or for further processing or action. Also used to denote the portion of the airborne transponder that interprets the jnterrogation code or mode received and instructs the transponder coder as to the type of reply to be sent.

Distributed ATC Managemcnt-System concept based on having some separntion and/or traffic management functions controlled by airborne pilots nnd some controlled by a ground agency.

Distance Measuring ***Equipment*** (DME)-Airborne and ground equipment used to measure, in nautical miles, the distance of an aircraft from a radio navigation aid.

DME Fix-A geographical position determined by reference to a radio navigation aid that provides distance and azimutb information; this position is defined by a specified distance in nautical miles and a radial in degrees magnetic from that aid.

Down Link-Aircraft-to-ground datn link.

En Route -ATC Service-Air traffic control provided for aircraft by centers on nn IFR flight plnn while these aircraft are opemting between departure and destination terminal areas.

Fail Soft-Systems capability in which operations continue, but with some degradation in capacity, when a failure hns occurred.

Fix--A geographical position determined by visual reference to the surface. by reference to one or more radio navigation aids, by celestial plotting, or by another navigational device.

Flight Plan-Specified information relating to the intended Flight of on aircraft; it is flied orally or in writing with an ATC facility.

Flight Path---The combination of altitude profile with horizontal track.

Fruit-See Nonsynchronous Garble.

Gain Time ***Control (GTC)-A*** ground receiver circuit that provides gain reduction as a function of time.

General Aviation-All aviation that are neither military nor commercial aviation.

Ground Collision Avoidance (GCA)-Provision for both strategic conflict avoidance and tactical collision avoidance from central ground jurisdictions by command control to aircraft.

Ground Controlled Approach (GCA)-An approach for landing which is largely directed by a ground controller.

Ground Derived-Information generated on the ground.

Holding - A predetermined maneuver which keeps an aircraft within a specified airspace (holding pattern) while awaiting further clearance.

Holding Fix---A specified fix used ns a reference point in establishing and maintaining the position of an aircrnft while holding.

Improved Side Lobe Suppression (ISLS)--A radar system that eliminates the effects of undesired reflection over the whole benm.

Instrument Flight-Flight in which the attitude, altitude and course of the aircmft is at all times mnintained by the pilot's reference to cockpit instruments.

Insfrument* Flight *Rules (IFR)-Flight in which the ATC system assures collision avoidance between aircraft op erating ***in*** accordance with IFR and CVR in Positive Controlled Airspace. When opemting outside **Positive** Control Airspace, pilot ***responsibility*** with respect to collision avoidance differs according to flight weather conditions. Instrument Flight Rules may be deflned differently in the 1980's than they are today.

Instrument Landing System (ILS)--8 runway nppronch system for unfnvorable weather conditions consisting of equipment both on the aircraft and on the ground. There are three basic systems on the ground : The localizer, which broadcasts a l00 MHz signal that locates the far end of the runway ;the glide slope, which broadcasts a 150 MHz signal from sides of the approach end of the runway and defines the limits within which the aircraft must be for proper approach ; and the extended center marker, which broadcasts at 75 MHz from severnl antennas defining the center of the extended ***runway.***

Interlace-To transmit different interrogntion modes on successive sweeps. See sweep.

Interleave- Transponder reply trains that overlap in time in such a way that no pulse from either train occurs at a possible pulse position in the other train.

Intcrmittcnt Positivc ***Control (IPC)-A data*** acquisition system that can reliably and accurately provide the ATC center with identity, position and altitude information on all aircraft within designated portions of the airspace. The ATC computer, through a data link, can automatically advise aircraft of threats due to other aircraft, weather. airspace boundaries nnd surface obstacles. The computer can also generate commands for appropriate evasive nnlncuvers. The system works on both controlled and uncontrolled aircraft.

Interrogation- Tansmission of a signal intended to trigger a transponder. Also called challenge and challenging system.

Intrudcr-- An aircraft which poses a collision threat to another aircraft by flying in airspace where it should not have entered or where it has not been cleared.

IR-Ground equipment that transmits the interrogation pulses and receives the corresponding reply pulses from airborne transponders.

Localizer- An ILS radio facility that provides signals for use in lateml guidance of aircraft with respect to a runway centerline.

Loron-- Originally standing for Long Range Navigation, it is a form of hyperbolic navigation in which a system of signals is transmitted as pulses. There are master stations each operating with one slave station. The difference in time **of** receipt of radio pulses from one such pair of stations is measured and the resultant time difference locates tbe aircraft on a hyperbolic line. When this is crossed with a second hyperbolic line from another pair of stations, a flx is obtained. Letter designations such as A, C, and D denote different broadcast operating frequencies.

Mark X SIF- The military version of the ***ATCRBS.***

Mil- An angular measurement now accepted as 1/6400th of a circle, or 3.375 minutes of angle. Originally. it was the angle that would subtend nn arc of one yard at a distance of 1000 yards.

Missed Approach- runway approach that must be aborted as a result of problems such as insufficient aircraft spacing, excessive crosstrack on approach velocity, or insufficient forward visibility.

Mixed Airspace-Airspace containing aircraft flying under either VFR or IFR. See ControlIed Air Space.

Mode 3A Interrogation-Civil and military interrogation of transponder asking for aircraft identification code.

Mode C Interrogation-Civil transponder interrogation asking for aircraft altitude.

Multipath-Electromagnetic energy arrival at a receiver via indirect path(s) from the source as a result of reflections from either the ground or from other external reflectors such as another aircraft, own aircraft structure, or buildings.

Mutual Interference -Any undesired reception of transmitted energy among elements of a group of cooperative stations. It occurs when groups of stations in close proximity use common or adjoining frequency bands in a system that has no specific provisions for multiplexing.

NAS Stage A and Stage B En Route System- An automated system of en route ATC providing alphanumeric information on en route radar displays. The present system (Stage A) will serve as the basis for the evolutionary growth of the future automoted system (Stage B). Additional systems to be incorporated include flow control, conflict detection and resolution, and electronic tabular displays.

Terminal System (NAS Stage A and ARTS III) - The automation being implemented in the present Third Generation System. The Committee feels that by expanding the semi-automation of NAS Stage A and ARTS III to include spacing, sequencing, and conflict prediction and resolution, and by adding data link, two or three times the present traffic could probably be handled by the same controller work force.

Navaid -Radio navigation aid.

Near-Midair Colliaion ***(NMAC)*** -A NMAC is considered to have taken place when two aircraft unintentionally pass within 250 feet of each other.

Noise Exposure Forecast (NEF)- A weighting system for measuring noise levels in the vicinity of airports.

Nonsynchronous Oarblc-Transponder responses inadvertently picked up by a given interrogator different from the one triggering the response. The result is that the ground station picks up a signal that is not synchronous with the interrogation signal. Also called total fruit.

NOTAM-Notice to airmen.

Null- A term applied to weak portions of an antenna radiation pattern. Nulls, in general, are small, typically subtending only a few square degrees.

Overflight Effects-The effect of a passing aircraft on an ILS localizer signal.

Overinterrogation-Excessive ground interrogation of a transponder; the result is a loss of reliability of information delivered to the ground station because of a lack of time within which the transponder can completely respond to a given interrogation.

Positive Controlled Airspace (PCA)-Exists above 18,000 feet in the northeastern portion of the United States and above 24,000 feet in the remainder of the country. In PCA all aircraft are under IFR control and the ATC system provides separation service between all aircraft.

Primary Radar-That form of radar that depends upon reception of reflected electromagnetic energy for the detection of objects in the area under surveillance.

Project Beacon- A scientific. engineering review of ATC conducted by the FAA at the request of President Kennedy in 1961. The review was also to prepare a practicable long-range plan to ensure efficient and snfe ATC.

Proximity (Pilot) Warning Indicator (PWI)- A pilot warning instrument which, in its most simple form, is an airborne device whose function is to warn a pilot of the proximity of other aircraft. It may also provide other information to assist the pilot in evaluating the situation, such as relative bearing and bearing rate of other aircraft, relative altitude, range, or combinations of these parameters. After visually locating the intruding aircraft, the pilot must evaluate the threat and select and execute an appropriate evasive action. A proximity warning system utilizing existing transponders has been suggested.

Radar--When appearing alone in this report. “radnr” is a general term applying to both primnry radar and transponder beacons.

Radar Beacon--A radar receiver-transmitter that transmits a strong coded signal whenever its receiver is triggered by an airborne interrogating radar. The coded reply can be used to determine position in terms of range and bearing from the beacon. Also called beacon. radar, and radar transponder.

Radar Identification-In ATC, radar identification is the process of ascertaining that n radar target is the radar return from a pnrticular aircrnft already in tbe ATC system or about to enter it.

Radio Beacon-A nondirectional radio transmitting station in a fixed geographic location, emitting a characteristic signal from which bearing information can be obtained by a radio direction finder on an aircraft.

Rango Ordering-A system used in digitizing whereby transponder signals are ordered in cells on the basis of range.

Receiving Path Side Lobe Suppression (RSLS) -Equipment that cancels replies received on the side lobes of the ground interrogator antenna.

Reflections-Spurious signals caused by interrogation or reply pulses which are reflected to the receivers from extraneous objects such as buildings, hills or other aircraft.

Resectorization--A permanent reorganization of the geographic sectors controlled by various ATC centers.

Retrofit- As applied to planes or air terminals, retrofit is the installation of new or improved systems designed to improve performance; e.g., retrofit of fan jet engines to a non-fan-jet aircraft, or the construction of a new runway pattern at an air terminal.

Rho-Theta System-A navigation system baaed on azimuth (theta) and range (rho) relative to a properly equipped radar center.

Roll Call- A sequential interrogation of approaching aircraft.-

Route- A defned path, consisting of one or more courses which an aircraft travels in a horizontal plane over the surface of the earth.

rss Expression -Root Sum Square mathematical expression. That is, the square root of the sum of the squares of several numbers.

Runway Number Designaticm- Numerical designation of runways-e.g., 4/22 runways-denotes the compass heading of a runway to the nearest 10 degrees. For example, 4/22 stands for 40 degrees and 220 degrees, where the 4 would designate the southwesterly approach to the runway (heading of 40 degree), and the 22 would designate the northeasterly approach (heading of 220 degrees). Further designations of L and R indicate the left or right sides of dual runvay systems.

Runway- Threshold-The physical beginning of a runway.

Satcllitc Airport- In many instances a community is served by severa1 airports, one of which serves a significant volume of air carrier and/or high performance military aircraft, while the others serve general aviation aircraft. These latter airports are "satellite airports.""

Scan-One complete circular, up-and-down, or slde-to-side sweep of the radar. light, or other beam or device used in making a scan.

See and Avoid--That type of flight opemtion in which pilots are required by Civil Air Regulations to avoid collision with other aircraft by observing specific right of way and other rules of flight. This is usually referred to as VFR flight.

Sensitivity Time Control (STC)- ***See Gain Time Control.***

Separation Minima- The minimum longitudinal, lateral, Or vertical distances by which aircraft are spaced through the application of ATC procedures.

Short Takeoff and Landing (STOL)-Aircraft that have performance characteristics requiring shorter runways than standard fixed-wing aircraft.

Side Lobe- Undesired radiation from a direotional radar antenna, as opposed to the antenna's main beam. The side lobes tend to give false position information as a result of extraneous reflections.

Side Lobe Suppression (SLS)-A signal generated to suppress the effects of side lobes. This is occasionally also nchieved by mechanical changes in antenna designs.

Side Effects- Terrain (or building) influences (reflections) on an ILS glide slope or localizer signals.

Spherics- An abbreviated form of atmospherics, it includes the radio-frequency electromagnetic radiation originating prlncipally in the irregular surges of charge in thunderstorm lighting discharges Spherics are heard as a background of crackling noise (static) in AM re ceivers. It is also called atmospheric interference, and is more prevalent and troublesome at lower frequencies.

Squitter-Random triggering of a transponder by extraneous noise.

Stationkeeping-Stationkeeping helps maintain order in a structured aircraft population, as in military formation or pattern flying. and can do the same in high density landing and take-off conditions at busy civilian airports, or en route in transatlantic air lanes. The stationkeep ing display is either a plan presentation of the relative positions of all aircraft or a flight director display indicating how to fly in order to maintain proper logitudinal, lateral, and vertical position relative to selected reference aircraft. The use of airborne stationkeepers enables aircraft to maintain safe relative positions and flight direction without visual contact: VFR spacings can be maintained more precisely with proper stationkeeping equipment than without. Stationkeeping can also be provided from a control ground station.

Swcep-One complete cycle of a radar system designed to cover or survey a certain area or volume of space, where the scan is accomplished by electrtronic means, mther than by mechanical motion of an antenna system, as in scanning radar. See Scan.

Synchronous Garble-Aircraft operating within approximately 1.66 n.m. slant range of each other and who are within the azimuth beamwidth of the interrogator can cause garble. During a garble situation, the individual pulses in the reply pulse trains from the two aircraft overlap, making it difficult (if not impossible) to determine which pulses belong in which code train.

Tactical Air Navigation (TACAN)-A system of navigation in which a single UHF transmitter sends out signals that actuate airborne equipment and provides range and bearing indications with respect to the transmitter locntion when interrogated by another transmitter on the aircraft. Each TACAN station broadcasts a location-identifying Morse code signal at regular intervals.

Terminal Area- Airspace and surface area. including airports, within a predesignated boundary and Up to a predesignated altitude above the surface.

Tower Bright Display- A radar-scope system designed to be viewed in a normally lighted room.

Track- The flight path of au aircraft over the surface of the earth.

Traffic Patton-The traffic flow that is prescribed for aircraft landing at taxiing on and taking off from an airport.

Transition Airspace-The boundary within which exists terminal airspace. Transit on airspace lies 40 to 60 miles from the terminal and is the area where an en route controlled aircraft will normally be held, when necessary, prior to commencing approach. It is the area of transition from en route ATC to approach ATC.

Transponder- An airborne automated mdar receiver-trnnsmitter from which a coded response is triggered by interrogntion from a ground transmitter. Response normally contains information on aircrnft identification, altitude and airspeed, nnd occasionally, heading, altitude rate, and position. See Interrogation.

Trigger Level- The threshold at which the transponder replies to 90 percent or more of the interrogntion.

Trilateration- A system by which an aircraft is located by DME relative to two separate known locations between which the distance is known. The resultant triangle precisely locates the aircrnft.

Tube-Predesignated three-dimensional path through airspace, normally assigned under high density and instrument flight conditions to aircraft having maximum equipment.

Uncontrolled Aircraft-Those aircraft not participating in or receiving traffic separation service from the ATC system. This term does not include those flights receiving control service from control towers having only visual surveillance in performing control service.

Uncontrolled Airspace-Underlies Controlled or Mixed Airspace. aircraft opernting solely in Uncontrolled Airspace nre not presently required to carry navigation, communications, or transponder equipment ; however, communications equipment meeting a limited chnnnel capability requirement is needed for operations conducted at a tower equipped field.

Vertical Takeoff and Landing (VTOL)--Aircraft which have performance characteristics permitting vertical or almost vertical takeoffs, landings, and climb and descent angles.

Vcry High Frequency Radio Onnirange (VoR)--A ground based radio station that propagates an unlimited number of "radials." On board an aircraft, the signals are converted to visual direction indications expressed as magnetic compass courses to and from the transmitter station.

VFR Highway- Predesignated route/altitude path through airspace used under visual flight conditions, by aircraft having minimum equipment.

Visual Flight Rules (VFR)--Visual flight in which avoidance of collision with other aircraft is dependent upon every pilot seeing other aircraft and avoiding them. To enable pilots to perform the collision avoidance function, the rules take certain weather conditions into account, and specify basic "rules of the air."

VORTAC - An nir navigation system combining VHF omnirange (VOR) and TACAN equipment.

Wave Off- A signal from the ground controller to the pilot that the landing should be aborted. Reasons for wave off may include runway congestion or poor separation of approaching aircraft.

Wind Rose- (1) A diagram showing the relative frequency and sometimes the average strength of the winds blowing from different directions in a specified region; (2) a diagram showing the average relation between winds from different directions and the occurrance of other meterological phenomena.

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ABBREVIATIONS

Asterisk (*) indicates that the term Is Listed in the Glosaary

AIA*-*American Institute of Aeronnutics
ALPA*-*Air Line Pilots Association
*AOC-Automatic Overload Control
AOPA-Aircraft Owners nnd Pilots Association
APC-Area Positive Control
ARO-Airport Reservation Offices
****ARSR- Air*** Route Surveillance Radar
ARTCC-Air Route Traffic Control Center
ARTS-Automatic Radnr Control Traffic System
****ASR- Airport*** Surveillance Radar
ATA-Air Transport Association of America
ATCAC-Air Traffic Control Advisory Committee
ATCRBS-Air Traffic Control Radar Beacon System
*CAS- Collision-Avoidance System
CONUS- Continental United States
CTOL-Conventional Take-Off and Landing
****CVR-Controlled*** Visual Rules
DAS-Data Acquisition System
DME- Distance Measuring Equipment
DOD-Department of Defense
DOT-Department of Transportation
ECAC-Electronmagnetic Compatibility Analysis Center
EPNL--Effective Perceived Noise Level
ERP-EffectiveRadiated Power
FL-Field Level
*GCA--Ground Controlled Approach; occasionally : Ground Collision Avoidance
G/S-Ground Station
*GTC- Gain Time Control
ICAO-International Civil Aviation Organlzntion
*IFR- Instrument Flight Rules
*ILS- Instrument Landing System
*IPC-Intermittant Positive Control
ISLS- Improved Side-Lobe Suppression
LOS-Line of Sight.
MAC-Midair Collision
MEA-Minimum En Route Altitude
MSL-Mean Sea Level
NAS- National Airspace System
NAS Stage A and ARTS III-National Airspace System and Automatic Radar Control Terminal System.
NBAA- National Business Aircraft Association
NEF- Noise Exposure Forecast
*NMAC-- Near Midair Collision
NPA-National Pilots Association
PAR-Precision Approach Radar
*PC Positive Controlled Airspace
prf-- pulse repetition frequency
*PWl- Proximity (pilot) Warning Indicator
RSLS-Receiving path side-lobe suppression
RTCA SC-117--Radio Technical Commission for Aeronautics, Special Committee 117. Special Committee 117 refers to a group working on improvement of ILS.
RVR-Runway Visibility Range
*SLS- Side-Lobe Suppression
STC- Sensitivity Time Control
*STOL---Short Takeoff and Landing
*TACAN-Tactlcal Air Navigation
*VFR- Visual Night Rules
****VOR-- Very*** High Frequency Omnirange
*VTOL-Vertical Takeoff and Landing

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